Research and Application of AC Motor Control on Vehicle-Mounted Dynamic Platforms: Postprint

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Abstract

The elastic deformation of vehicle tires and suspension components in a vehicle-mounted dynamic base can introduce disturbances into fast servo control systems. Through analysis of the impact of vehicle body disturbances on motor control systems, this paper identifies the key technologies for addressing the high-precision requirements of dynamic base motor servo systems as: measuring the natural vibration frequency of the vehicle chassis suspension system, and designing low-pass filters and servo control strategies based on disturbance data. Simulations were performed on a motor servo system installed on a dynamic base, and the aforementioned research findings were applied to this system. The final experimental results of the servo system demonstrate that the vehicle chassis frequency measurements, designed filters, and servo control strategies presented herein effectively suppress the influence of vehicle body disturbances on AC servo motors, with control accuracy meeting system requirements.

Full Text

Preamble

Servomotor' s Control Research and Application on Vehicle-Mounted Moving Base

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Abstract

The elastic deformation of vehicle tires and suspension components on a moving base creates disturbances in rapid servo control systems. This paper analyzes the influence of vehicle disturbances on motor control systems and identifies the key technologies for achieving high-precision servo control on moving bases: measuring the natural vibration frequency of the vehicle chassis suspension system, designing low-pass filters based on disturbance data, and developing appropriate servo control strategies. Using a motor servo system installed on a moving base as a case study, system simulations were conducted and the research findings were applied to the actual system. Experimental results demonstrate that the measured chassis frequencies, designed filters, and servo control strategy effectively suppress the influence of vehicle disturbances on AC servo motors, meeting the system' s precision requirements.

Keywords: Vehicle-mounted moving base, vehicle disturbance, AC motor, servo control system

1 Introduction

To effectively counter threats from precision strikes and low/ultra-low altitude penetration, modern weapon systems demand enhanced rapid response capabilities and self-survivability to seize combat opportunities and intercept incoming targets while on the move. Consequently, the ability to achieve stable aiming during brief stops—and even high-precision control while moving—has become essential for terminal air defense weapons.

With advances in modern mechanization, target mobility has reached new levels, imposing higher performance requirements on stabilization and tracking equipment [1-4]. To meet the demands of high-precision control during short stops and while moving, vehicle chassis cannot be equipped with leveling systems, which introduces a critical challenge: the elastic deformation of vehicle tires and suspension components creates disturbances in rapid servo control. Similar issues exist in shipboard motor servo systems, but wave disturbances are relatively easier to suppress due to their low frequency, with multiple successful domestic cases already implemented. However, vehicle disturbances contain more high-frequency components, making them significantly more difficult to mitigate.

Traditional vehicle-mounted servo systems had lower precision requirements, focusing primarily on ensuring smooth motor operation with static error and dynamic tracking performance that satisfied overall control system demands.

2 Research and Analysis of Vehicle Disturbance and Natural Frequency

Disturbances from vehicle-mounted moving bases affect servo system control, necessitating analysis of their impact and particularly the role of the vehicle' s natural frequency.

2.1 Impact of Vehicle Disturbance on Servo Systems

The control principle of motor servo systems uses the error between target commands and current position as input, calculates control quantities through intelligent control algorithms, and thereby controls the motion of the controlled object. For servo systems installed on vehicle-mounted moving bases, target commands incorporate vehicle attitude changes. Specifically, a positioning and orientation device installed on the vehicle chassis continuously collects information on yaw, pitch, and roll. The fire control system converts this three-dimensional information into elevation and azimuth data that is added to the target commands sent to the servo system. The high-frequency disturbance components in these target commands adversely affect servo control.

These effects manifest in two primary ways: (1) During system start and stop instants, the chassis becomes an elastic base due to tire construction, making it difficult to rapidly dissipate kinetic energy. While servo systems on fixed platforms can quickly attenuate kinetic energy changes through rigid bases, the elastic characteristics of vehicle-mounted bases cause kinetic energy variations to induce tire and suspension vibrations that require considerable time to decay. (2) Due to the chassis's inherent natural frequencies, the servo system's resonant frequency decreases because of changes in base dynamic characteristics, reducing servo bandwidth and consequently diminishing the system' s ability to control high-frequency disturbances.

All these effects require prior measurement and analysis of the natural frequencies of the vehicle suspension and tires to avoid the vehicle' s natural frequency bands during control and achieve satisfactory performance. Currently, multiple domestic organizations are researching high-precision motor control systems for short stops and moving conditions, but control results remain unsatisfactory, with most servo systems achieving only 0.3° precision or worse.

One particular project, due to its special requirements, demanded servo system precision of 0.15°. During system maneuvering, chassis attitude variations could reach 0.2°. Without compensation for disturbances caused by chassis elastic deformation, servo precision cannot meet system requirements. Moreover, failure to effectively avoid the vehicle' s natural frequencies in servo control could lead to resonance between the servo system and vehicle. Therefore, measuring the modal shapes and natural vibration frequencies of the vehicle chassis suspension system under its specific stiffness and damping, collecting vehicle attitude data during servo operation, identifying appropriate filtering methods, selecting suitable servo control strategies, and compensating the filtered data constitute the key technologies for achieving high-precision servo system performance on moving bases [5-11].

2.2 Vehicle Natural Frequency Measurement and Analysis

This paper analyzes the influence of vehicle disturbance on motor servo systems and determines that measuring the natural frequencies of the vehicle suspension and tires is essential for avoiding the vehicle' s natural frequency bands during control. Based on the measured vibration frequencies, a Butterworth filter was selected as the low-pass filter for this system, and a composite control algorithm integrating feedforward control from classical control theory with fuzzy parameter self-tuning was adopted as the servo control strategy. Control system simulations were performed, and the research findings were ultimately applied to a vehicle-mounted motor servo control system.

Four test points were established on the front and rear sections of the chassis main beam, with acceleration sensors installed at each point. The vehicle' s frequencies were tested using a road drop method, with results shown in Figure 1 [Figure 1: see original paper]. Analysis revealed that the first-order vibration frequency of the vehicle suspension system' s spring-damper was 2.41 Hz, while other vibration frequencies correspond to the first six natural frequencies of the suspension and main beam structures at 6.78 Hz, 12.70 Hz, 38.84 Hz, 54.42 Hz, 77.64 Hz, and 108.5 Hz. These measurement results directly guide the design of the servo system control bandwidth.

3 Research on Filtering Algorithms for Vehicle Disturbance Data

After obtaining the vehicle' s natural frequencies, the cutoff frequency for filtering vehicle attitude data during servo operation can be determined, and an appropriate filtering algorithm must be selected.

Among low-pass filter options, common choices such as Kalman filters, Chebyshev filters, and Butterworth filters can all serve as software filters. The original Kalman filter has evolved into various improved forms including Schmidt extended filters and square-root filters. These filters utilize linear system state equations to optimally estimate system states from input-output observation data. However, Kalman filters involve substantial computation and are better suited for offline system state estimation. Chebyshev filters exhibit equal ripple in the passband or stopband, providing smaller errors compared to ideal filter responses, but simulations revealed significant phase lag. Butterworth filters feature maximally flat frequency response curves in the passband without ripples, with gradual attenuation to zero in the stopband—characteristics well-suited for this system. Therefore, the Butterworth filter was selected as the low-pass filtering algorithm, using the resonant frequency of 2 Hz as the cutoff point to filter target data received by the servo software, removing high-frequency components from vehicle attitude information and compensating only low-frequency data to avoid resonant effects.

A fourth-order Butterworth filter was designed for this system, with the following transfer function used for simulation:

$$G(z) = \frac{0.002235(z+1)^4}{(z^2 - 1.213z + 0.384)(z^2 - 1.48z + 0.6887)}$$

The filtering effects for elevation and azimuth disturbances are shown in Figures 2 [Figure 2: see original paper] and 3 [Figure 3: see original paper], respectively, demonstrating significant low-pass filtering performance.

4 Determination of Motor Servo Control Strategy and Simulation Results

Based on analysis of disturbance data precision requirements, a composite control algorithm integrating feedforward control from classical control theory with fuzzy parameter self-tuning was adopted as the servo control strategy. A simulation model was built in Matlab using an AC motor model, with filtered data used as input commands for simulation. The basic simulation structure is shown in Figure 4 [Figure 4: see original paper].

Simulation results are presented in Figures 5 [Figure 5: see original paper] and 6 [Figure 6: see original paper] (only azimuth results are shown due to space limitations). During normal tracking, both sinusoidal and constant-speed tracking errors remained within 0.1°. The constant-speed tracking curve for azimuth is shown in Figure 7 [Figure 7: see original paper].

5 Specific Servo System Design

Based on vehicle frequency test results, data filtering, and algorithm simulation, a specific servo system was designed. Using filtered data as input commands for the servo control algorithm significantly reduces the impact of high-frequency components on control performance, enabling compensation of only low-frequency data and avoiding resonant effects.

The servo system consists of a PowerPC controller, signal control unit, motor, motor driver, position sensors, safety mechanisms, and control software. The controlled object is a launch device installed on a vehicle chassis. A positioning and orientation device on the chassis continuously collects vehicle attitude information. The fire control system generates target commands by combining radar data with vehicle attitude information. The PowerPC controller receives these commands via CAN bus, applies Butterworth filtering, receives motor position information, and calculates control quantities based on command and position data. Elevation and azimuth position sensors communicate with the controller through CAN interfaces to transmit position information. The servo control software employs intelligent control algorithms; after calculation by the PowerPC controller, control signals are converted to analog signals via D/A conversion boards to drive motor rotation. The signal detection unit collects safety signals such as limit switches to provide data for safety design. The overall servo system block diagram is shown in Figure 8 [Figure 8: see original paper].

In the servo control software, a fourth-order Butterworth filter was implemented to process fire control commands, achieving filtering effects similar to simulations and providing clear high-frequency disturbance suppression. To address the problem of kinetic energy variations causing tire and suspension vibrations that require extended decay time, current loop and control algorithm parameters were optimized by extending motor acceleration/deceleration times, increasing integral constants, and smoothing control quantities to improve overall system performance.

6 Experimental Validation Results

After commissioning, the servo system ultimately met all requirements, achieving static accuracy of 0.05° and dynamic tracking accuracy of 0.15°, satisfying the overall system' s precision control requirements for short-stop operations. Figures 9 [Figure 9: see original paper] and 10 [Figure 10: see original paper] show the waveform results during sinusoidal and constant-speed motions.

7 Conclusion

This paper analyzes the influence of vehicle disturbance on motor servo systems and identifies the key technologies for high-precision motor control on vehicle-mounted moving bases: measuring natural frequencies of vehicle suspension and tires, designing filtering algorithms, and developing servo control strategies. Research, measurement, and testing were conducted on these three key elements, with results applied to a vehicle-mounted motor servo control system. System tests demonstrate that the filters and servo control strategy effectively suppress vehicle disturbance effects on the motor system, with servo control precision meeting system requirements. These research findings provide valuable reference for implementing high-precision servo systems for moving platforms.

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Note: Figure translations are in progress. See original paper for figures.