High-Frequency BLDC Feedforward Control and Optimization for Motion Control

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Compared to common open-loop stepper motors, 3-Phase synchronous motors can deliver superior responsiveness, repeatability, and speed with minimal noise, wear, and heat. Brushless DC (BLDC) motors, the most affordable and accessible type, have trapezoidal back electromotive forces rather than the optimal sinusoidal shape, causing cogging torque. These harmonic attractive forces between the rotor and the stator make them unoptimized for precise motion control by default. To solve this, a unique position controller method using feedforward velocity compensation is developed. Instead of the industry standard configuration of 2 PI loops (each for D-Axis and Q-Axis current control) and a velocity PID loop, the motor is commutated at a constant voltage (or theoretical velocity) using efficient SVPWM inverter voltage control. Back-EMF is integrated into the current limiting model to maximize angular velocity while remaining within the current limit. To solve nonlinearities in actual velocity caused by cogging torque, a physical model of the system is created by deriving feedforward (compensatory) voltage from acceleration (torque). Since the moment of inertia (used in the above physical model) is often challenging to calculate, a P controller (iterative learning control) is proposed that converges to the correct feedforward map. Within minutes, cogging torque is reduced by 95% according to the low-frequency cogging harmonics on a velocity versus position Fourier Transform. All research was performed on real equipment. In combination with a highly-optimized 20khz (50 microsecond period) PID position loop, this economical $40 closed-loop BLDC servo motor achieves positional bandwidth and stiffness comparable to $500-$2000 industrial servos.

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