Control Technologies Utilized in the Servo Systems

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1. Introduction

Servo systems provide the "muscle" for motion control systems – allowing the system to operate as directed. The Servo system consists of a motor and an amplifier. A machine is usually attached to the motor and it must function as directed. Our challenge is to control the machine while accounting for disturbance, mechanical resonance, and friction effects. The innovative application of control theory is invaluable in achieving these demands. Control theory is shifting from classical control that centers on PID control to modern control techniques including observers. In addition, control theory has also adopted digital control technology in recent years. This paper introduces the control technology developed for the new Q series, our latest servo system.

2. Control Technology in the Q Series

The newly developed Q series servo system was aimed at high accuracy, high response, and high efficiency. In the Q series, we adopted the modern control theory, which is represented by the observer, and system identification theory that includes the PI control to achieve high performance.

2.1 High Accuracy and High Efficiency Torque Control

The heart of the torque control is the current control. In the Q series, the current control is greatly enhanced by increasing the PWM frequency to twice the conventional frequency and reducing the current loop sampling cycle by half. This has doubled the current loop response as compared to the conventional product. Moreover, the d-q axis control has become more accurate by adding a deviation compensation for the d-axis current. A torque control system is used to control these d-q axis currents resulting in the best possible torque. In the past, field-weakening control had been used in high-speed applications according to the rotation speed. However, we have improved this method by reducing the d-axis current when the torque is small by including the torque command into the control function. As a result, motor current during no-load operation was decreased and power loss was reduced. A highly effective torque control was achieved while improving the efficiency of the motor and while decreasing the losses in the main circuit semiconductor.

2.2 Command Tracking Control

The position and speed control system is enhanced by the improved torque control resulting in superior command tracking performance. High response is another feature that has been achieved by cutting the sampling cycle in half. As a result, response of the speed control system achieved 600 Hz, 1.5 times more than the conventional product as shown in Fig.1. In addition, when the speed control of the machine is observed, there is significant improvement in the position settling time. Fig.2 is the position settling time measured with load inertia applied to the motor. The settling time of 0.6ms is obtained with a positioning complete width of 12 pulses. The hit rate in the PTP (point to point) control has improved considerably because position settling time has been shortened, motor power rate has been doubled, and the maximum rotation speed had been improved to 5000 min^{-1}.

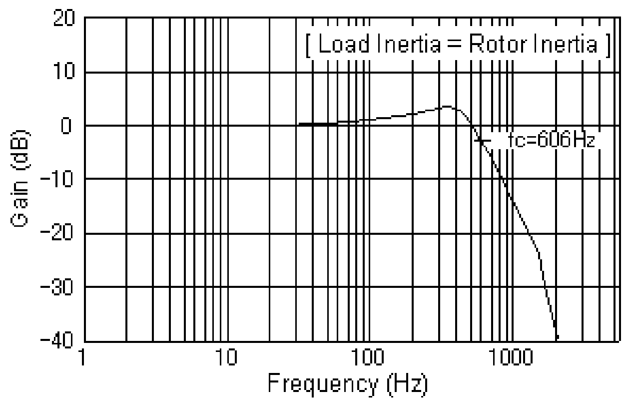

Fig.1 Speed Frequency Response

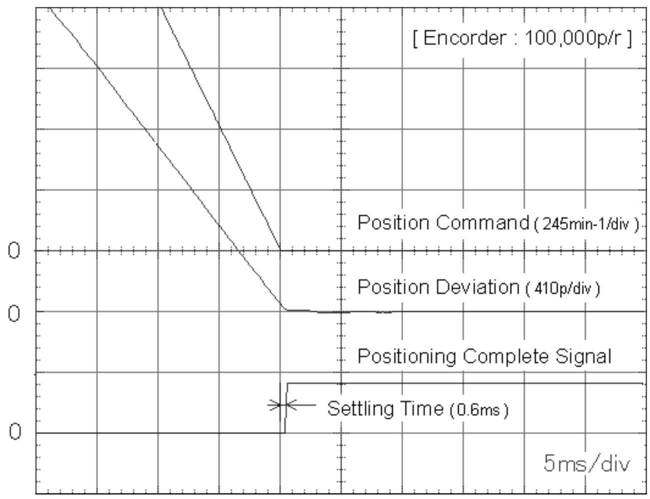

Fig.2 Position Settling Characteristics

As for position control of a machine, precise tracking is possible as well. The tracking performance of the position control using the CP control has been doubled as compared to the conventional product. Moreover, a control mode where the regular deviation becomes zero can be selected. Fig.3 shows the position deflection with this mode of operation.

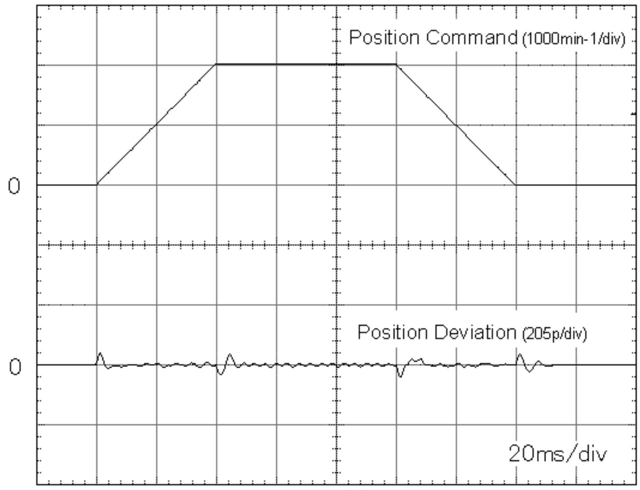

Fig.3 Deviation Minimization Control Characteristics

In addition, the encoder resolution has been greatly increased to improve the positioning accuracy. The incremental encoder has 8,000 P/R (after multiplying by four) for the conventional system while the new system has 16,384 P/R (after multiplying by four). An absolute encoder is also available with resolution improved from 13 to 17 bits in the conventional product to 21 bits in the new product. Even the motor has cogging torque that is 1/3 of the conventional motor. A smooth and highly accurate control has been achieved because of the improvement in encoder resolution and decrease in the motor cogging torque. A final benefit is the new incremental encoder with a parallel communication method – a real improvement in easy hook-up.

2.3 Disturbance Suppression

An observer has been utilized to minimize any disturbance through the use of high gain speed control. The observer calculates load torque using the motor speed and the torque command and minimizes disturbance by adding compensation to the torque command. This results in a 2-degree-of-freedom control system where the command response and the disturbance response can be independently adjusted. Fig.4 shows the change in the speed after a load torque equivalent to the rated torque is applied to the motor rotating at 10 min^{-1}. Fig.4 shows that there was almost no speed change when the disturbance suppression compensation was active while speed did change without the disturbance compensation during the application and removal of load torque.

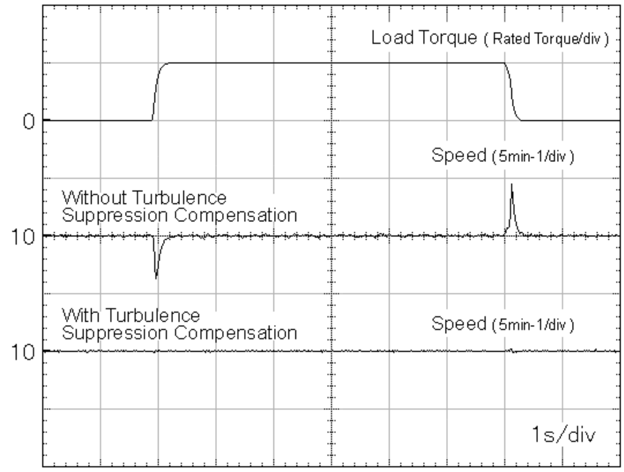

Fig.4 Disturbance Suppression Characteristics

2.4 Vibration Control

The performance of machine systems with high drive rigidity has been greatly improved including the new servo system. However, recent machine objectives are high-speed and low-cost so machines with a lower rigidity is increasing. The two-inertia system can be used as a model for machines with low rigidity. Fig.5 shows the structure with the motor connected to the load through a twisted spring system. The load will vibrate in such a two-inertia system as the motor tries to improve the target tracking performance or the disturbance suppression performance. This vibration is undesirable because the purpose of the control is to move the load according to the command. So, the new servo system is equipped with vibration control, which extracts the vibration element using a sensor and controls the vibration through added compensation in the control system. A higher response characteristic can be obtained as compared with the conventional product thanks to this vibration control, and the tracking performance can be improved even in the machine with a low rigidity. In addition, a second order notch filter is provided to reduce vibration at frequencies where application of the sensor is difficult. The range of frequencies that the new notch filter can handle is doubled at the high end while it is lowered by 50% at the low end. In addition, a low-pass filter on the torque command can be applied at higher frequencies. The new Q series has increased the order of this low-pass filter to provide a sharper cut-off characteristic.

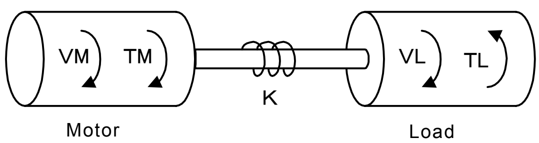

Fig.5 Two Body Inertia System

2.5 Analysis of Machine Characteristics

Vibration control requires knowledge of the resonance frequency and the anti-resonance frequency. In the Q series, we have developed software that is able to analyze the frequency response characteristics of the machine system using a personal computer. The combination of a random signal as a torque instruction and FFT (Fast Fourier Transform) to process the speed signal results in a measurement of the frequency characteristic. This measurement can be executed in a few seconds and the machine characteristics can be determined faster than a conventional analyzer.

2.6 Auto Tuning

The main objective of the Q series was stability so we improved the capability of our auto-tuning capability. The auto-tuning "measures" the load inertia to self-adjust the control parameters. Stability has been enhanced by a factor of 5 over the conventional product by improving the algorithm even though the estimation of the inertia becomes difficult during low acceleration / deceleration condition. In addition, the range of estimation for the inertia ratio has been expanded from 31 times to as much as 127 times. Also, the algorithm was modified so that the control system adapts to any changes in the estimated inertia. The result is a more general auto-tuning capability with a wider range of applications as compared with the conventional product.

3. Conclusion

The control technology of our new Q series was outlined in this paper. The features of the Q series control technology are as follows.

- High accuracy and high efficiency torque control
- Command tracking control
  (speed frequency response up to 600Hz with position settling time of 1ms or less)
  (position control tracking performance in CP control is up to twice that of our conventional product)
- Smooth rotation as a result of high-resolution encoder and low cogging motor
- High stiffness control using a disturbance sensor
- Reduction of machine vibration by vibration control sensor, wide range 2nd order notch filter, and higher-order torque command low-pass filter
- Determination of the machine characteristic
- Performance improvement of the real-time auto tuning

The Q series drives can be used for both rotary motors and linear motors. Noticeable performance improvement is achieved with application to semiconductor manufacturing equipment, chip mounters, and machine tools.

The performance requirement of the servo system is more demanding each year. Fortunately, the control theory is evolving rapidly too. We will continuously make every effort to apply new control theory and to construct a servo system that will suit many types of machines.

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