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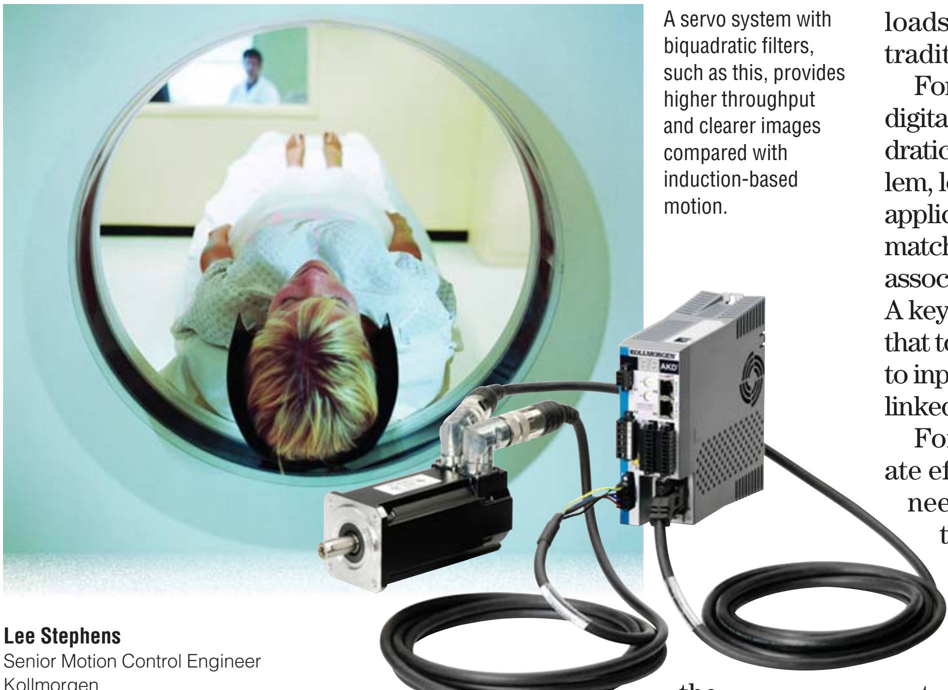
Servo motors with digital filters speed medical imaging



A servo system with biquadratic filters, such as this, provides higher throughput and clearer images compared with induction-based motion.

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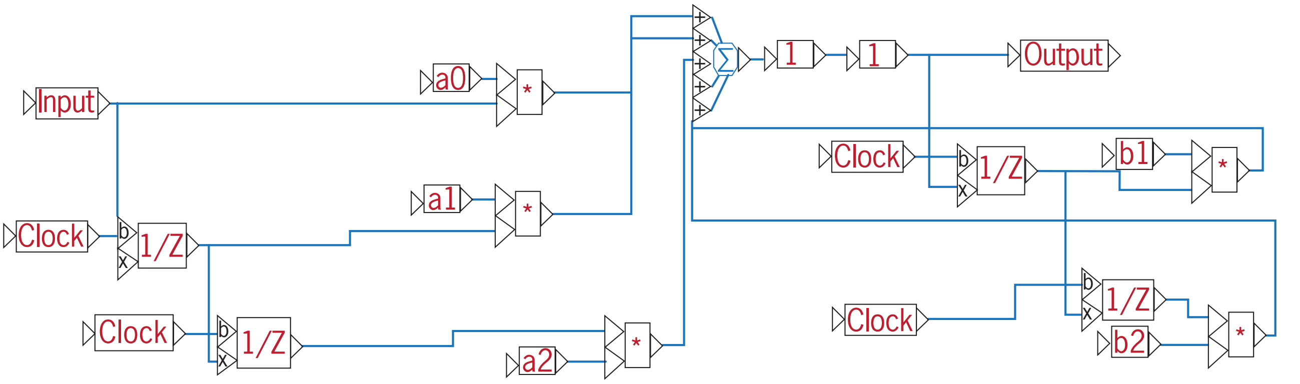
The motion control system has become one of the most important components in supporting the automation of medical imaging systems because it provides quick scan times and high image quality. As a result, medical-device OEMs need alternatives to the relatively slow and inaccurate AC induction motors traditionally used to position imaging gantries in equipment such as x-ray, computed tomography (CT), and positron emission tomography computed tomorgraphy (PET-CT) machines. Indeed, servo motors work well for fast and accurate positioning. But the high inertial loads of medical gantries have traditionally restricted their use.

Fortunately, a new generation of digital drives with advanced biquadratic filters addresses this problem, letting servo motors work in applications with inertial-load mismatches of up to 1000:1 and their associated resonance challenges. A key advantage of these motors is that torque is directly proportional to input current while speed is linked to input voltage.

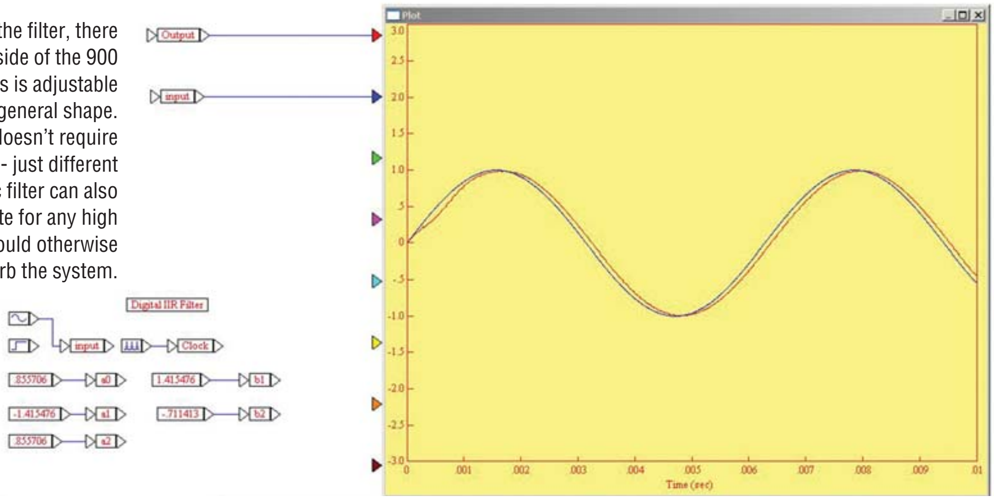
For servo systems to operate effectively, servo amplifiers need to be tuned to optimize the system's response. This often involves increasing the gain. However, adding too much gain leads to instability and even uncontrollable oscillation. Instability can result in overshoot with respect to the speed for which the motor has been given a command.

A control system is "out of control" when the gain is -3 dB or less, or the output phase is -45° or less from the control signal, or -135° relative to a reference from the motor. The open-loop transfer function is well known to predict the maxi-



The block diagram shows the layout of a biquadratic filter.

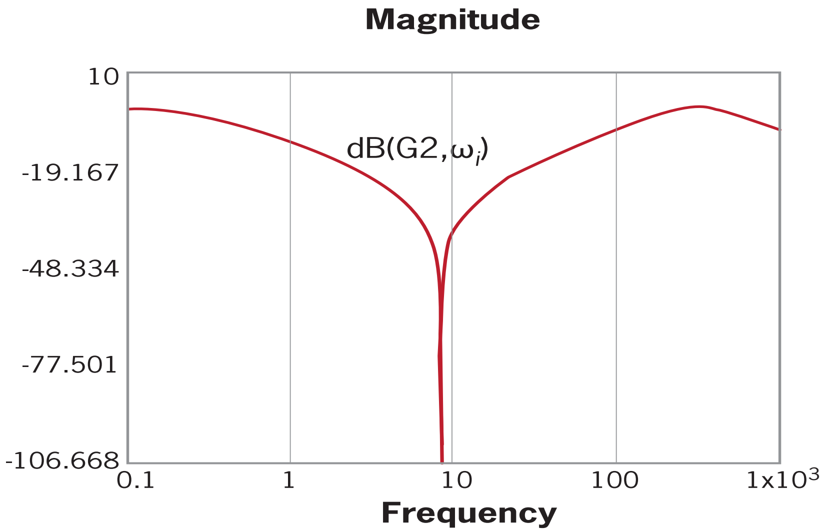
With a lower frequency entering the filter, there is very little disturbance outside of the 900 Hz point. This lowering of gains is adjustable for width, depth of cut, and general shape. Additionally, the variance doesn't require any cascading of more filters - just different coefficients. The biquadratic filter can also automatically accommodate for any high frequency resonance that could otherwise potentially disturb the system.



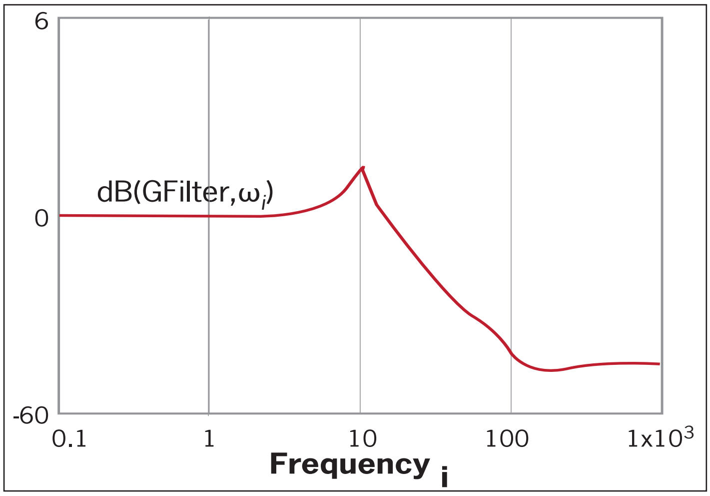
mum performance of a system. (An open-loop transfer function is the mathematical analysis of a system without feedback consideration; it is used to determine the forward loop components.) The closed loop stability problems can be predicted as well using two measures: phase margin (PM) and gain margin (GM). PM is the difference of -180° and the phase of the open loop at the frequency where the gain is 0 dB. GM is the negative of the gain of the open loop at the frequency where the phase crosses through -180°. The greater the unpredictability of the load, the higher GM and PM need to be to ensure the stability of the control system.

For example, when the resonant frequency is well below the first phase crossover (270 Hz), the effect of the compliant load is to reduce the GM. (A load is compliant when it is connected to a motor with a system or device that is not rigid. All things have compliance so the term is often relative. Belt coupled systems are compliant while direct coupled motors are considered stiff or rigid. "Stiffness' is the opposing torque to unwanted movement, measured in N/M or Nm/radian normally.) If the inertia mismatch is 5, the reduction of GM will be 6, or about 16 dB. Assuming no other remedy is available, the gain of the compliantly coupled system would have to be reduced by 16 compared to the rigid system, assuming both would maintain the same GM. Such a large reduction in gain would translate to a system with much poorer command and disturbance response.

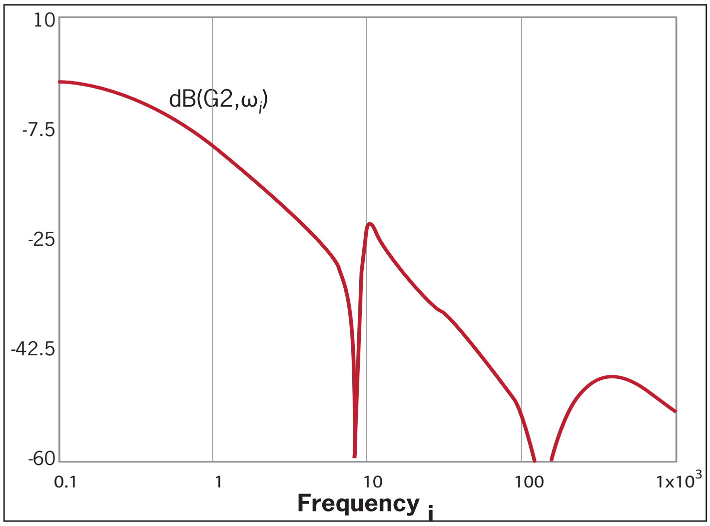
As mentioned, servos can now compensate for inertial mismatches and compliant loads. Servo manufacturers' effort to this end have been based on the fact that compliant mechanical systems typically have a few resonant points prone to oscillations, while performance is much better at other frequencies. The traditional approach here is to use low-pass, band-pass, and high-pass filters to eliminate unwanted frequencies. The problem with this approach: Multiple filters are needed to eliminate resonances (which introduce calculation delays) and phase shifts (which have a tendency to throw



The graphic illustrates the transfer function of a system handling a large load. The system is peaking at approximately 135 Hz. Attempting to increase gain at this frequency would result in instability and oscillation. However, using a simple biquadratic filter provides superior gain margin by simultaneously boosting the lower frequencies while cutting the higher frequencies. So boosting the 10 Hz range and reducing the 135 Hz range is accomplished via the coefficients of the digital filter.



With a biquadratic filter employed, this graphic illustrates what the transfer function might look like.



When a biquadratic filter is incorporated into the transfer function of a resonant system, high frequencies are cut and obtaining a flat response is possible with much higher gain. In this example, the resonant peak is reduced by more than 40 dB. Thus the proportional gain could be increased, which equates to higher frequency response and stiffer systems.

the system out of control).

Here is where the biquadratic filters come into play. A biquadratic filter consists of two quadratic equations with five coefficients so it can emulate nearly any combination of simpler filters without introducing significant delays. By tuning out problematic frequencies, the biquadratic filter makes it possible to increase the PM and GM to optimize servo system performance. For example, if the mechanical system has a 200 Hz resonance, the biquadratic filter can be configured to remove 200 Hz while keeping the gain at the much lower control frequencies high.

It's important to note that large belt-driven gantries have a strong physical roll-off that makes them act as a low-pass filter that cuts off everything above approximately 10 Hz. By cutting the gain at 10 Hz while passing the velocity loop between 30 and 40 Hz, the biquadratic filter makes it possible to substantially increase the gain at the critical control frequencies of around 2 to 4 Hz.

Velocity feedback in combination with the biquadratic filter provides dramatic improvement for systems with unwanted low-frequency resonance. Compared to the traditional solution of a single-pole low-pass filter, settling time is cut by a factor of three and the bandwidth raised by the same factor. At the same time, feedback maintains the stability margin with acceleration and jerk forces are substantially reduced.

The latest generation of servo controls can be configured to provide the GM and PM needed to compensate for the high inertial loads and compliance involved in medical imaging applications. An additional benefit: Leading servo manufacturers have implemented manufacturing efficiency improvements that have reduced the cost of servos to that of AC induction motors.