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SERVO TRENDS

JULY 2011, VOL. 26 NO. 3

QUARTERLY NEWSLETTER PUBLISHED BY GALIL MOTION CONTROL

"The mission of Galil's experienced Applications Department is to provide prompt and accurate technical assistance to help OEMs successfully deliver their products to market."

GALIL SUPPORT TEAM

New Frequency Analysis Software Allows Servo Tuning in Frequency Domain

In most cases tuning servo systems in the time domain works well; as is evidenced by GalilTools software which performs automatic servo tuning quickly and easily for Galil controllers. However, there are some cases where designers prefer to work in the frequency domain. Tuning in the frequency domain is often preferred for systems with resonances or when the design engineer is comfortable with classroom control theory.

To address this need, Galil is introducing Frequency Analysis Software, a tool for tuning servo control systems in the frequency domain. The software in conjunction with a Galil motion controller measures the frequency response of the plant to be controlled. It simulates the possible control solutions and synthesizes the two to allow for Bode analysis of the closed loop system.

This article reviews frequency domain terminology, presents the steps for tuning using Galil's new Frequency Analysis Software and shows an example of using the software for tuning a brushless motor with a Galil DMC-4010 motion controller.

Introduction to Frequency Domain Terminology

The elements of a typical servo system are shown in the block diagram of ***Figure 1*** *(page 2)*. The motion controller includes the digital PID filter and DAC. The other elements of the system are defined as the plant and include the amplifier, motor, load and encoder. The amplifier converts the current command to the appropriate voltage and current to drive the motor which in turn moves the load. The position of the motor or load is measured by a digital encoder which is fed back into the controller. The closed-loop system of the controller and plant is shown in ***Figure 2*** *(page 2)*. Note that the encoder position is compared with the command position to form the closed-loop position error which is input into the digital filter and plant.

➤(cont. pg 2)

Figure 1: Block Diagram of Servo System

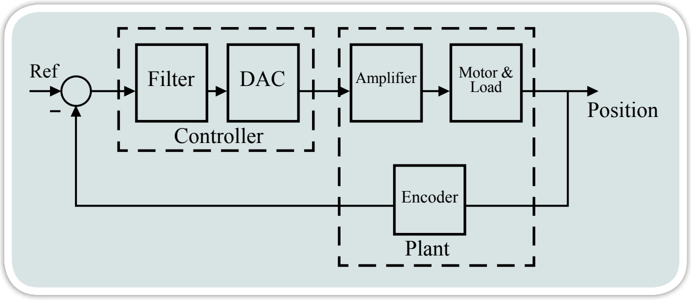


Figure 2: Closed-Loop System of Controller and Plant

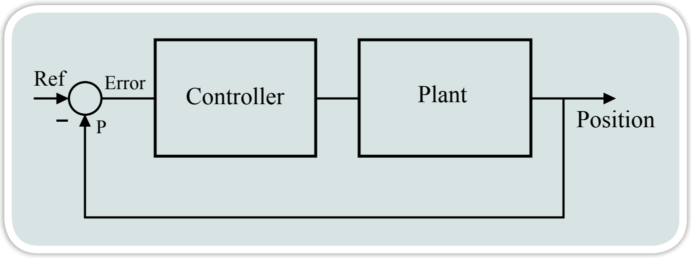


Figure 3: Bode Plot as generated by Frequency Analysis Software

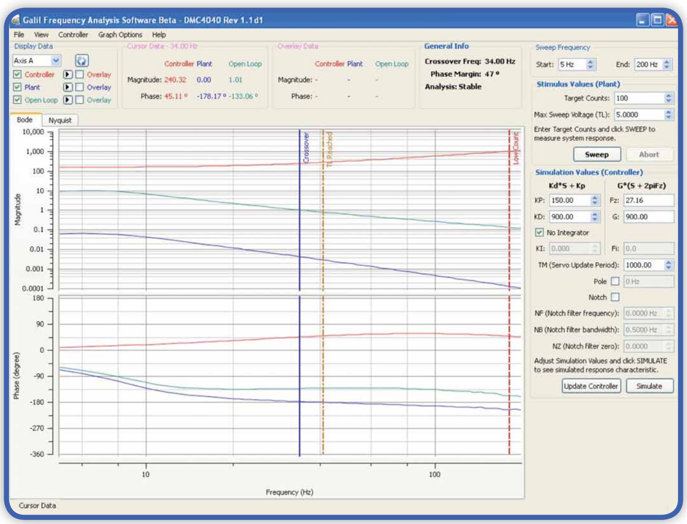
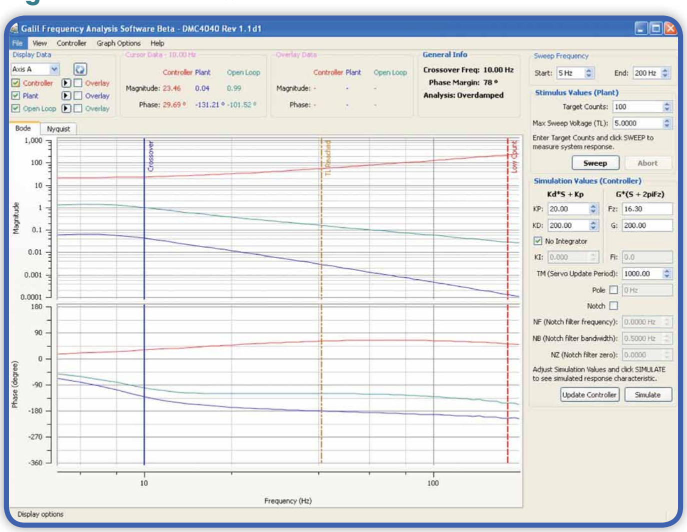


Figure 4: Bode Plot with KP of 20 and KD of 200



A linear system in the frequency domain is described by a transfer function in which each element of the system's frequency response is given as a function of the Laplace variable "s". The variable "s" can also be represented as "jω" where j is the imaginary unit and ω is the frequency. Since the resulting function is a complex number with real and imaginary parts, it is most convenient to present it by its magnitude and its phase shift in a graphical form which is known as a Bode plot. The Bode Plot is a set of logarithmic graphs of the transfer function of a system versus the frequency. The Bode Plot consists of two graphs: the magnitude and phase.

Galil's Frequency Analysis Software plots the magnitude versus frequency and phase versus frequency for both the controller and the plant. The plant's frequency response is measured from the actual plant. The controller's response is simulated based on the selected control parameters. The product of the two functions is the system open loop frequency response. An example Bode plot generated by the Frequency Analysis Software is shown in ***Figure 3***.

The critical parameters of the frequency response which allows the designer to analyze the system performance are the crossover frequency, ω_C, and the phase margin. The crossover frequency also known as the unity-gain frequency is that frequency where the open loop gain equals one. The higher the crossover frequency, the faster the system response and the higher the closed loop bandwidth will be.

Of course, it is not enough for the closed loop bandwidth to be high; the system must also be stable. This is where phase margin enters the picture. The extent to which the phase of the loop frequency response at the unity gain frequency exceeds -180 degrees is called the phase margin. If the phase at the unity gain frequency is less than or equal to -180 degrees (phase margin is 0 or negative) the system will be unstable. A system with a small phase margin will be very under-damped. A good rule of thumb is to have a system with a phase margin of 45.

Tuning in the Frequency Domain

The Frequency Analysis Software (FAS) allows the designer to try various simulations of the controller parameters such as the PID filter and notch parameters and combine them with the plant to give the open loop frequency response. Based on the simulations, the designer can determine the best controller parameters to meet the desired performance criteria of phase margin and cross-over frequency for his system.

The steps for tuning in the frequency domain are as follows:

1. Set the desired target magnitude (in counts) and the desired range of frequencies to sweep.
2. Use FAS to measure the frequency response of the plant by pressing SWEEP. This process typically takes about a minute and only needs to be done once. The system will vibrate in response to the specified stimulus.
3. Select the desired cross over frequency and phase margin of the open loop system.
4. Experimentally choose the KP and KD parameters which will give an acceptable phase margin (typically 45 degrees) at the desired cross over frequency.
5. Use FAS to SIMULATE the open loop response. Look at the phase margin and cross over frequency on the Bode Plots and repeat steps 4 and 5 until the desired response is observed.
6. If a resonance is observed in Step 2, put in a Notch or Low Pass filter in the controller at the frequency at which the resonance occurs.
7. Add KI if desired to eliminate position error at rest making sure to readjust parameters if the cross-over frequency and phase margin are effected.

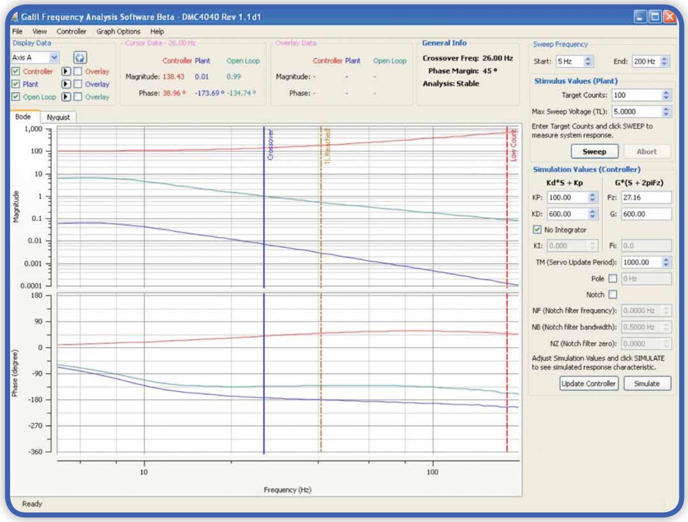
Example

Galil's BLM-N23 brushless motor and DMC-4010 motion controller with -D3020 brushless drive is used in this example. The desired cross-over frequency is approximately 25Hz with a phase margin above 45 degrees.

The DMC-4010 motion controller is connected to the FAS software using the Connect to Controller button and communication between the software and controller is verified.

1. Set a Sweep frequency range of 5 to 200Hz and a target magnitude of 100cts
2. Press SWEEP. The resulting frequency response plots of the plant are shown in ***Figure 4*** *(page 2)*
3. Desired Cross-over frequency is at least 25Hz and phase margin at least 45 degrees
4. Try KP 20 and KD 200. Press Simulate. ***Figure 4*** *(page 2)* shows that cross over frequency and phase margin are not as desired. Increase PID parameters to KP 100, KD 600. Press Simulate. The resulting frequency response is shown in ***Figure 5*** and meets desired criteria. ■

Figure 5: Bode Plot with KP of 100 and KD of 600



Trapezoidal vs. Sinusoidal Brushless Amplifiers

The new Galil Sine drive amplifiers are a welcome addition to the existing DMC-40x0 and DMC-41x3 line-up of servo and stepper amplifiers—yet the addition of the new amplifiers also brings up a question—"When should I use a sinusoidal drive instead of a trapezoidal drive?" This article will go over the Galil brushless servo drive architecture and highlight what you should know when making an amplifier selection.

Two Loop Architecture

In order to gain a better understanding of servo amplifiers and specifically how the Galil servo amplifiers work, the first thing to do is to understand the Controller/Amplifier architecture. Unlike most single axis drives on the market, Galil uses a split sample rate. The first and highest speed sample rate occurs on the amplifier and is used on the current loop. The D3540 Sinusoidal amplifier runs its current loop at 33 kHz and the D3040 Trapezoidal amplifier runs at 66 kHz (which can be increased to 120 kHz for low inductance applications). The benefits of a high speed current loop are:

- Fast response to desired current/velocity command signal
- Less destabilizing phase shift on the position loop
- Tighter more accurate control – 16bit resolution
- High Closed Loop Frequency (3-4 kHz)

The second loop in the system is the position loop. Because of the limitations of real world mechanics, a position loop generally has a closed loop frequency in the range of 20 to 200 Hz. The sample rate required to achieve this is only from 1 kHz to 4 kHz. Note that the DMC-4000 can have a sample rate of up to 16 kHz and can control up to 8 axes allowing all axes to be tightly coupled. General motion control applications run optimally at a 1 kHz position loop update. High performance and high resolution applications can be run at higher rates depending on the required performance.

Separate processors for the Amplifier and Controller allow for this two loop Architecture which allows Galil to be extremely responsive and highly accurate and also perform whatever functions are required in a user's application.

Trapezoidal vs. Sinusoidal Commutation

Trapezoidal commutation is the most cost effective way of controlling a brushless servo motor. It is perfect for higher speed applications and applications where the motor and mechanics will eliminate the torque ripple that occurs during switching current from one phase to the next. Hall sensors are required for Trapezoidal commutation.

Sinusoidal commutation is great for lower speed, direct drive or linear motor applications where the torque ripple of the motor phases needs to be minimized. Since the current to the motor phases are weighted as sine waves, the torque going through the motor is smooth and has minimal ripple. It also allows the mechanics to be simplified because Hall sensors can be eliminated.

Sinusoidal amplifiers rely on an initialization sequence at power-up to provide the correct commutation. This can be done in one of 3 ways on the Galil. The first and most common method is the BX command that uses an algorithm that energizes the phases and determines the brushless angle. Only a small amount of motion (if any) is shown with this method. The second method is to use the BC command that requires Hall sensors to be hooked up. It will move the motor and use the first hall transition as the basis for the commutation. This method is necessary if there is an external force on the motor such as a gravity load. The third method uses the BZ command to drive the motor to the zero degree commutation point which can result in a jump to the closest zero phase. For detailed information on getting started with the Galil Sine Drives, please visit:
http://www.galilmc.com/support/appnotes/accelera/note1501.pdf

More info on Galil Sinusoidal Amplifiers

The new AMP-43540 drives four brushless motors operating at up to 8 Amps continuous, 15 Amps peak, 20-80 VDC. The gain settings of the amplifier are user-programmable at 0.4, 0.8, and 1.6 Amp/Volt. The amplifier offers protection for over-voltage, under-voltage, over-current, short-circuit and over temperature. A shunt regulator option is available. For more information, please visit: *http://www.galilmc.com/products/dmc-40x0.php* ■

Galil. We Move the World.

With over 500,000 controllers installed worldwide, Galil is the leading supplier of motion controllers. Galil's legacy of innovation began in 1983 with the introduction of the first microprocessor-based servo motion controller. Today, Galil continues its leadership by offering the most powerful, cost-effective and easy-to-use controllers to accommodate all your motion and I/O needs.

Galil offers a broad array of motion controllers in a variety of formats: single and multi-axis, card-level and box-level, bus-based and stand-alone. Galil's Ethernet/RS232 and PCI controllers are available in an Econo version for lowest cost and Accelera version for ultra high-speed performance. Plug-in, multi-axis drives for steppers and servos save space, cost and wiring. For intelligent I/O control, the RIO Pocket PLC is compact, low-cost and packed with analog and digital I/O.

At Galil, we share our expertise with our customers. You will find a wealth of information on our website at http://www.galilmc.com. Here you can view any of Galil's free web-tutorials, read an application note or white paper, post a question on our bulletin board, or download the latest software and manuals.

Exceptional application support is a top priority at Galil. Call Galil today at 800-377-6329 to discuss your project with one of our highly-trained applications engineers. ■

ACCELERA CONTROLLERS AND DRIVES	
DMC-40x0	Ethernet/RS232
DMC-18x6	PCI

ECONO CONTROLLERS AND DRIVES	
DMC-41x3	Ethernet/USB/RS232 — **New!**
DMC-21x3	Ethernet/RS232
DMC-18x2	PCI

SINGLE-AXIS CONTROLLERS AND DRIVES	
DMC-1415	Ethernet/RS232
CDS-3310	Ethernet/RS232

POCKET PLC I/O CONTROLLER	
RIO-47xxx	Ethernet/RS232

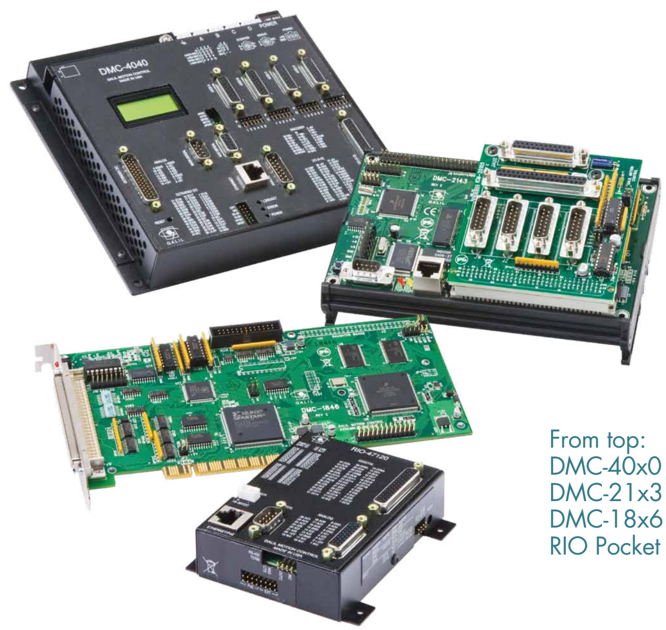
SOFTWARE TOOLS

GalilTools. Servo Tuning and analysis software

Frequency Analysis Software. Performs Servo Tuning in the frequency domain. — **New!**

Ladder Interface. Converts Ladder program into DMC code for RIO Pocket PLC.

Galil PVT. Software tool for PVT mode of motion.



From top:
DMC-40x0 Accelera Controller
DMC-21x3 Econo Controller
DMC-18x6 PCI Controller
RIO Pocket PLC

FREE	Online Support Tools
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