



# SERVO TRENDS

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## QUARTERLY NEWSLETTER PUBLISHED BY GALIL MOTION CONTROL

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“ 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



## Achieving Ultra-Fast, Precision Motion with Galil Controller and Schneberger Linear Stage

By Todd Shearer, Application Engineer

### Introduction

Motion control applications typically fall into one of two categories: 1) high speed and high throughput with less stringent accuracy requirements, or 2) lower speed with very high accuracy requirements. However, sometimes an application requires both high speed as well as high accuracy, and when such an application arises, it requires all motion components to be of the highest performance. This was the case for a manufacturer in the automotive test equipment industry.

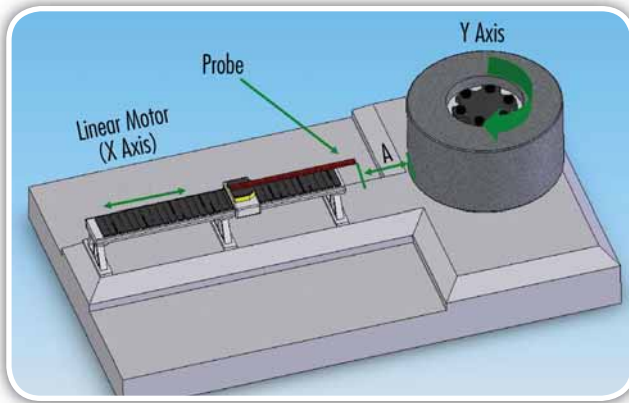
The application was for the redesign of an existing machine used to test automotive sensor components. The test measurements required extremely short and accurate moves to test the quality of the sensor. In addition, high throughput was required due to the large number of test moves to be performed.

The resulting stringent specification involved making a .001" move in 1-2 msec that settled within a window of no more than +/-0.0005" and had an overshoot of less than 0.0005". To meet this challenge, Galil’s DMC-40x0 controller was selected in an open competition for this business, along with a Schneberger linear motor stage and Copley digital amplifier.

### Application Description

In this application, the machine is used for testing the sensitivity of a particular automotive sensor. To do so, there are two critical axes on the machine: a rotary motor moving a drum at constant velocity, and a linear motor which moves the sensor in incremental steps towards the rotating drum. *Figure 1* (on page 2) shows a drawing of the machine.

►(cont. pg 2)



**Figure 1:** Machine layout (critical axes)

The step moves of the linear motor (distance "A" in **Figure 1**) range from a minimum of 0.001" up to 0.511". The goal is for the motor to be moved and settled within a position window in a time of 1-2 msec per 0.001". A 0.001" move should take 1-2 msec, while a 0.01" move should take no more than 10-20 msec. The motor must be settled within a window of no more than  $\pm 0.0005$ " as it would invalidate the test measurement. A PLC in the system will interface with the Galil controller to command the absolute position where the motor is to move. Once settled, the Galil hand-shakes back with the PLC indicating motion is complete and the position at which it's settled.

### Controller Competition

The customer specification of 1-2 msec for a complete 0.001" move was a target for all potential solutions. It was not a given that any combination of controller, amplifier and motor would be able to meet this specification. Consequently, the customer decided to open the competition to three major control manufacturers who were challenged to prove their system best capable of achieving the greatest performance while also offering ease of use, a competitive price and good technical support.



The competition was set up to see which controller/motor combination gave the best performance at various benchmarks. Move and settle times were measured for linear moves of 0.001", 0.002", 0.004", 0.008", 0.016", 0.032", 0.064" and 0.128". Motion was considered complete when the motor was in the position window of  $\pm 0.0005$ ".

### Galil Setup and Results

The Galil DMC-4040 controller was selected for this application based on its high servo bandwidth (up to 32 kHz) and ability to take feedback from a sine/cosine encoder and interpolate at a selected resolution. The controller also gave the customer the required number of I/O points along with the stand-alone Ethernet capability they required.

As mentioned, the Galil controller was paired with a high performance Schneeburger linear

stage and Copley digital amplifier. The linear stage was solidly mounted to a granite base, and provided extremely fast, linear response to a control input. The digital amplifier was tuned for a very high current loop bandwidth so it could respond quickly to the Galil control input.

Setup and tuning of the system with regards to the Galil controller had two major portions. First, the sine/cosine Heidenhain encoder had to be connected to the interpolation board found within the Galil controller. This sine/cosine interpolation enables the user to select an interpolation resolution from 32-4096x. For this application, an interpolation of 64x was sufficient, giving a positional accuracy of 0.3125  $\mu$ m. Next, the PID filter was tuned for optimum performance. From testing, it was found that a servo update rate of 16 kHz was a sufficiently fast time base for this system, so the TM value was set to 62.5  $\mu$ sec. Also, Galil implemented an additional tuning command to gain slightly more performance out of the system and contribute to the final successful results. The chart below shows the filter gains and motion parameters used for this system:

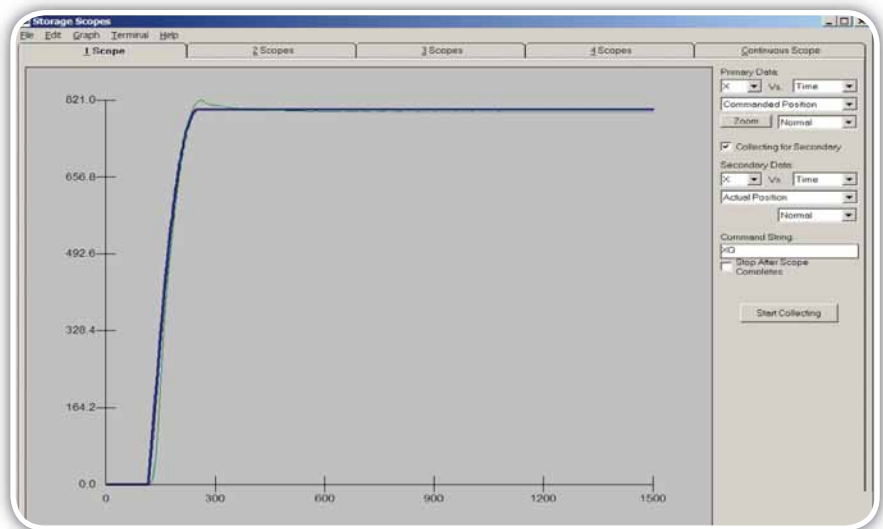
Parameter	Galil command	Comments
Servo bandwidth	TM62.5	62.5 $\mu$ sec gives a 16 kHz servo bandwidth
Encoder interpolation	AF6	2 <sup>6</sup> interpolation (64x) of the sin/cos encoder, yielding 0.3125 $\mu$ m on a 20 $\mu$ m pitch scale
Proportional gain	KP35	
Integral gain	KI0.01	
Derivative gain	KD4000	
Integrator limit	IL-1	Limits Integral term to 1V and freezes while profiling
Feedforward acceleration	FA4	
Feedforward deceleration	FD8	Custom command added for this application
Pole Filter	PLO.75	Low pass filter used to remove high frequency resonances
Speed	SP250000	Motor speed of 250,000 counts/sec
Acceleration	AC650000000	Acceleration of 650,000,000 counts/sec <sup>2</sup>
Deceleration	DC15000000	Deceleration of 15,000,000 counts/sec <sup>2</sup>

With these numbers, the Galil controller met or exceeded the customer requirements at all move distances. In addition, Galil's controller exceeded the performance of both competitors as shown in the customer supplied results below:

Move distance	0.001"	0.002"	0.004"	0.008"	0.016"	0.032"	0.064"	0.128"
Current app (msec)	4.5	8	13.7	21	31	45.6	71	121.3
Galil (msec)	1.7	2.45	4.9	8.7	11	16	26	46
Competitor 1 (msec)	3.5	5	6	8	17	21	37	76
Competitor 2 (msec)	4.95	6.9	9	12.7	17.2	25.4	41.2	72.3

## Conclusion

Galil's DMC-40x0 is a proven high performance motion controller, capable of meeting or exceeding the performance of the most demanding application. In this application, Galil won the business over two major competitors, one a dedicated controller company with a reputation for the highest performance in the industry, the other being the largest name in the PLC/automation industry. After the customer completed their testing, Galil rated #1 in performance and for ease-of-use in programming. ■



WSDK screen capture showing a sample Galil move profile

## Modes of Motion Zone: Electronic CAM

By John Minotti, Application Engineer

In this article, Electronic CAM (ECAM) is discussed. ECAM mimics the behavior of a mechanical CAM by driving a slave axis along a predetermined profile based on the position of a master axis. As a result, ECAM is well suited for applications that require an axis to follow a repeatable, non-linear profile coordinated to the position of another axis. This differs from electronic gearing where the relationship between the axes is a fixed ratio such as the X-axis always moving half the distance of the Y-axis.

With ECAM, the relationship between the master and slave axes is nonlinear where the master axis provides reference points that coordinate with the location of the slave axis. This is done by building a table of positions that define the motion profile that the slave will follow. As the master axis passes through user defined position intervals, the slave will simultaneously reach the respective slave positions assigned by the table commanding it to follow the desired motion profile. This

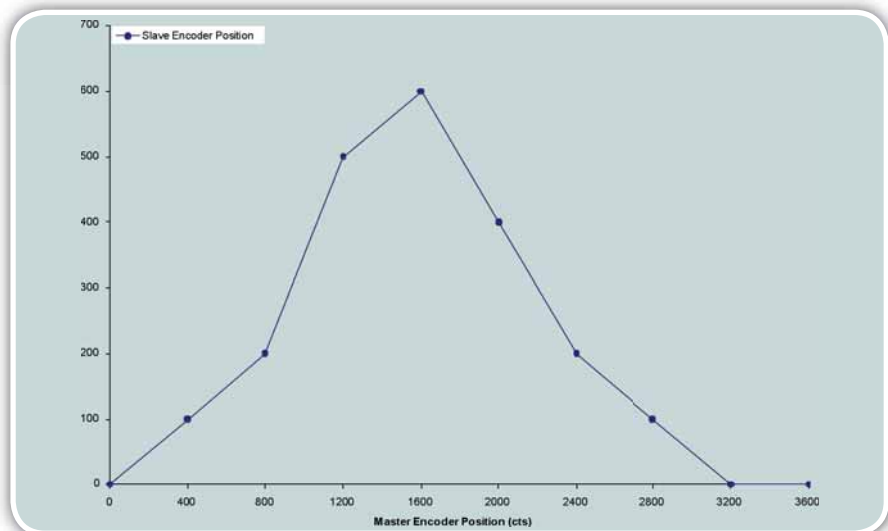


Figure 1: Graph of the ECAM slave position profile vs the master position

behavior is illustrated in *Figure 1*, where the position of the slave axis, graphed along the vertical axis, is driven to the locations shown in *Table 1* as the master axis passes through each position interval, graphed along the horizontal axis.

► (cont. pg 4)

ECAM Point #	Master Axis Position (cts)	Slave Position (cts)
1	0	0
2	400	100
3	800	200
4	1200	500
5	1600	600
6	2000	400
7	2400	200
8	2800	100
9	3200	0
10	3600	0

Table 1: Table of slave positions, the corresponding master positions and ECAM point numbers. This particular table corresponds to an ECAM set up that has a modulus of 3600 points, and a master interval of 200.



### Dual ECAM

Using a single ECAM table is adequate for most applications requiring nonlinear motion coordination. However, some applications require the profile of a slave axis to change between ECAM cycles, requiring two ECAM tables. A specialized ECAM mode, called Dual ECAM, allows the slave axis to alternate between two ECAM tables every other cycle. This results in the slave axis changing its motion profile every other ECAM cycle. Single table ECAM is available on all Galil controllers as a standard feature. Dual ECAM comes standard with Galil Accelera controllers and as an option on Galil's other controllers.

### ECAM Implementation

Programming ECAM using Galil controllers requires three parameters to be specified:

1. ECAM modulus (EM) - the displacement of the master axis that corresponds to one complete cycle of the ECAM table.
2. ECAM interval (EP) – the displacement of the master axis between each of the slave positions.
3. ECAM table (ET) - the table of slave axis positions.

The first step in programming ECAM is to build the ECAM table that defines the profile of the slave axis. Next, the position increment of the master that will pass between each slave position must be defined. With the interval and number of ECAM table positions, the modulo can be calculated as follows:

$$EM = EP * ET_{dim}$$

Where:

EM=Master Modulo

EP=Master Interval

ET<sub>dim</sub>=ECAM Table Dimension or Number of ECAM Table Points

One behavior of ECAM worth noting is that the master interval corresponds to absolute position increments. This means that regardless of master axis direction or speed, the slave axis will follow accordingly, essentially coordinating with any speed and direction of the master.

### Example ECAM Application

An example of an application requiring Dual ECAM is a stamping machine where metal is fed continuously and two different patterns are stamped along the face of the sheet. Dual ECAM is necessary because the stamping process operates continuously and requires two different profiles to be stamped into the metal. Dual ECAM allows switching between the two profiles without disrupting the continuous feed of the metal sheet.

For this example, the X-axis is the slave (stamping apparatus) and the Y-axis is the master (sheet metal feed). The Y-axis is geared to a dummy axis Z with a ratio of 1. The Z-axis is used to mimic a constant feedback for the master to follow. In an actual system, the Z feedback could be a production line, motor velocity or anything that the ECAM needs to be coordinated with. The master axis can also simply be an axis under Galil control or can be feedback from an external source. These last two options eliminate the need for the dummy axis.

The Dual ECAM mode not only allows two discrete ECAM profiles to be prescribed, but also allows the ECAM profiles to be

changed without disengaging the ECAM mode or stopping motion. This is accomplished by loading a new ECAM table during the execution of the other. Dual ECAM builds the two ECAM tables as standard Galil arrays or ECAM arrays stored in standard array space. As the code executes, it loads the other array in alternating order into the ECAM table. Alternating the ECAM tables creates two distinct motion profiles for the slave axis to follow.

The Galil DMC code used for this application is shown at the end of this article. The parameters in the program are defined as follows:

Etbl1 and Etbl2: The ECAM Array designations.

VI: Termination variable, which upon changing its value will execute a termination loop to stop the program in a predefined manner. This is necessary to allow for any command to start properly upon subsequent execution.

Master1, Master2, Slave1, Slave2: Variables used to set the controller modulus and adjust the master interval accordingly and on the fly.

#W0: Program loop that is used to ensure that the ECAM has been engaged before starting the execution of the ECAM table.

#W1: Program loop that is used to hold code execution of the next ECAM table until the previous cycle has been completed. This is done by stalling the code until half of the previous ECAM

►(cont. pg 5)



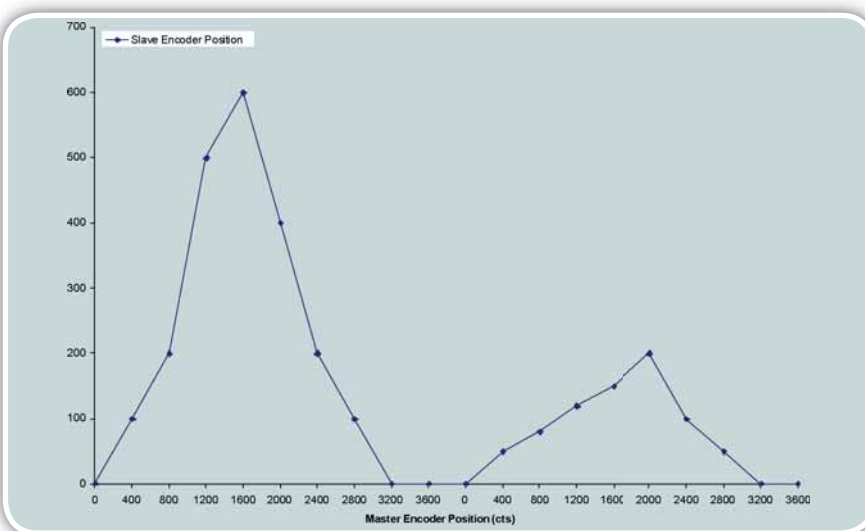
table has been executed. After that, an ECAM disengagement point (90% of the ECAM table) is set and the code waits for disengagement before proceeding.

The program works by initializing and running the first ECAM table in standard ECAM mode. The ECAM tables are loaded by referencing the ECAM arrays. After the first ECAM profile has been executed, the ECAM mode is disengaged per the sequence and timing of the #W0 and #W1 loops. These loops are necessary to wait for certain events to be completed before proceeding. This eliminates any race conditions caused by code executing too fast after the ECAM table has been disengaged.

After the ECAM mode has been disengaged, the modulus for the proceeding table must be entered. Following the loading of the ECAM modulus, the second ECAM table is loaded and executed in the same manner as the first table. In addition to prescribing the two discrete ECAM profiles, this code allows for the ECAM profiles to be changed without disengaging the ECAM mode or stopping the motion. This is easily done by issuing a new point or points to one of the ECAM arrays. These points will then be referenced during the execution of the next cycle, which changes the profile. The ECAM modulus can also be changed without stopping the motion code by changing the value of the variables Master1, Master2, Slave1 and Slave2. These variables define the master and slave ECAM modulus (EM). The code automatically adjusts the ECAM interval (EP), per the modulo setting.

In this example, there are a series of ECAM table points of 0. This provides a dwell in the ECAM function while the new ECAM table is loaded. This dwell is necessary because the controller's processor is occupied with the loading of the new table which would stall the ECAM profiling at the last point reached. By including this dwell period, the axis can be returned to a predicted and controlled location during the loading of the new table. The necessary dwell time depends on table size and master encoder velocity, both of which will vary from application

►(cont. pg 6)



**Figure 2:** Multiple (dual) ECAM profile using two ECAM tables on the same set of axes. Note the cyclic rollover of the master encoder axis at the modulo of 3600 encoder counts. This illustrates 2 ECAM profiles being applied to the same master/slave axis pair.

ECAM Point #	Master Axis Position (cts)	Slave Position (cts)
1	0	0
2	400	100
3	800	200
4	1200	500
5	1600	600
6	2000	400
7	2400	200
8	2800	100
9	3200	0
10	3600	0

**Table 2:** First table of slave positions and the corresponding master positions and ECAM point numbers. This particular table corresponds to an ECAM set up that has a modulus of 3600 points, and a master interval of 200.

ECAM Point #	Master Axis Position (cts)	Slave Position (cts)
1	0	0
2	400	50
3	800	80
4	1200	120
5	1600	150
6	2000	200
7	2400	100
8	2800	50
9	3200	0
10	3600	0

**Table 3:** Second table of slave positions and the corresponding master positions and ECAM point numbers. The modulo and master interval is the same for this table as the first.



to application. For example, running this code as a single thread on a DMC-4020 Accelera controller, a 10-point ECAM table required just 1.95 ms to load. With a 100-point ECAM table only 4.9 ms was necessary. For the maximum size of 257 ECAM points, only 12.5 ms was needed.

**Figure 2** (on page 5) illustrates the profile that results from the use of Dual ECAM functionality, following the positions listed in **Table 2 and 3** (on page 5).

### Conclusion

The ECAM mode of motion is useful for applications where a slave axis needs to follow a master axis based on a prescribed table. Dual ECAM allows for two different tables to be followed without pausing motion. Galil's motion controllers provide the ECAM mode of motion as a standard feature. Dual ECAM

►(cont. pg 7)

## Dual-ECAM DMC Code

```
#CAM
DA*,*[];          'DEALLOCATE ARRAYS AND VARIABLES
MG*V1=1 TO DISABLE'; 'TERMINATION VARIABLE INSTRUCTION
V1=0;             'ENABLE TERMINATION VARIABLE
Master=4096;      'MASTER ENCODER MODULO
Slave=8000;       'SLAVE MODULO
#ARRAY;
DMEib1[1[0],Eib12[10]; 'DIMENSIONING TABLES
Eib1[0]=0;        'BUILDING TABLE FOR INITIAL MOVEMENT
Eib1[1]=100
Eib1[2]=200
Eib1[3]=500
Eib1[4]=600
Eib1[5]=500
Eib1[6]=200
Eib1[7]=100
Eib1[8]=0
Eib1[9]=0

Eib12[0]=0
Eib12[1]=50
Eib12[2]=80
Eib12[3]=120
Eib12[4]=150
Eib12[5]=200
Eib12[6]=100
Eib12[7]=50
Eib12[8]=0
Eib12[9]=0

DPO,0,0;          'SET POSITIONS TO ZERO
SHXYZ;           'CLEAR POSITION ERROR
GAY=CZ;          'USED TO KEEP MASTER UNPROFILED
GRY=1;           'GEAR RATIO FOR UNPROFILED MASTER AXIS
JGZ=1000;BGZ;    'JOG DUMMY AXIS TO DRIVE MASTER ENCODER
WT10;            'SMALL DELAY TO ALLOW MASTER MODULO TO BE NON ZERO

#CA
EAY;             'Y AXIS ECAM MASTER
EM Slave,/Master; 'SET ECAM MODULOS
EP Master,/10,0; 'SET ECAM TABLE DELTA
EB1;            'START ECAM MODE
#L1;            'LOAD ARRAY1 INTO ECAM TABLE
                ►(cont. next column)

ET[0]=Eib1[0]
ET[1]=Eib1[1]
ET[2]=Eib1[2]
ET[3]=Eib1[3]
ET[4]=Eib1[4]
ET[5]=Eib1[5]
ET[6]=Eib1[6]
ET[7]=Eib1[7]
ET[8]=Eib1[8]
ET[9]=Eib1[9]

EGO;             'ECAM GO
#W0;P#W0,_LEGX=0; 'WAIT FOR ECAM TO BE ENGAGED
#W1;P#W1,_LTPY<(|Master*.5); 'SAME AS MF TRIPPOINT
EQ(|Master*.9);  'DISENGAGE ECAM AT % OF MASTER
#W2;P#W2,_LEGX=1; 'WAIT FOR ECAM TO DISENGAGE

#L2;             'LOAD ARRAY2 INTO ECAM TABLE

ET[0]=Eib12[0]
ET[1]=Eib12[1]
ET[2]=Eib12[2]
ET[3]=Eib12[3]
ET[4]=Eib12[4]
ET[5]=Eib12[5]
ET[6]=Eib12[6]
ET[7]=Eib12[7]
ET[8]=Eib12[8]
ET[9]=Eib12[9]

EGO
#W3;P#W3,_LEGX=0
#W4;P#W4,_LTPY<(|Master*.5))
EQ(|Master*.9)
#W5;P#W5,_LEGX=1

JP#L1,V1=0;      'LOOP UNLESS OPERATOR SETS V1
EBO;            'STOP ECAM MODE
STYZ;          'STOP DUMMY AXIS
```



is a standard feature on Accelera controllers. For additional information on ECAM and Dual ECAM refer to Application note 2510 and 2441 at:

<http://www.galilmc.com/support/appnotes/accelera/note2510.pdf>

and:

<http://www.galilmc.com/support/appnotes/optima/note2441.pdf> ■

## Galil Motion Control Celebrates 25th Anniversary of Shipping Their First Motion Controller

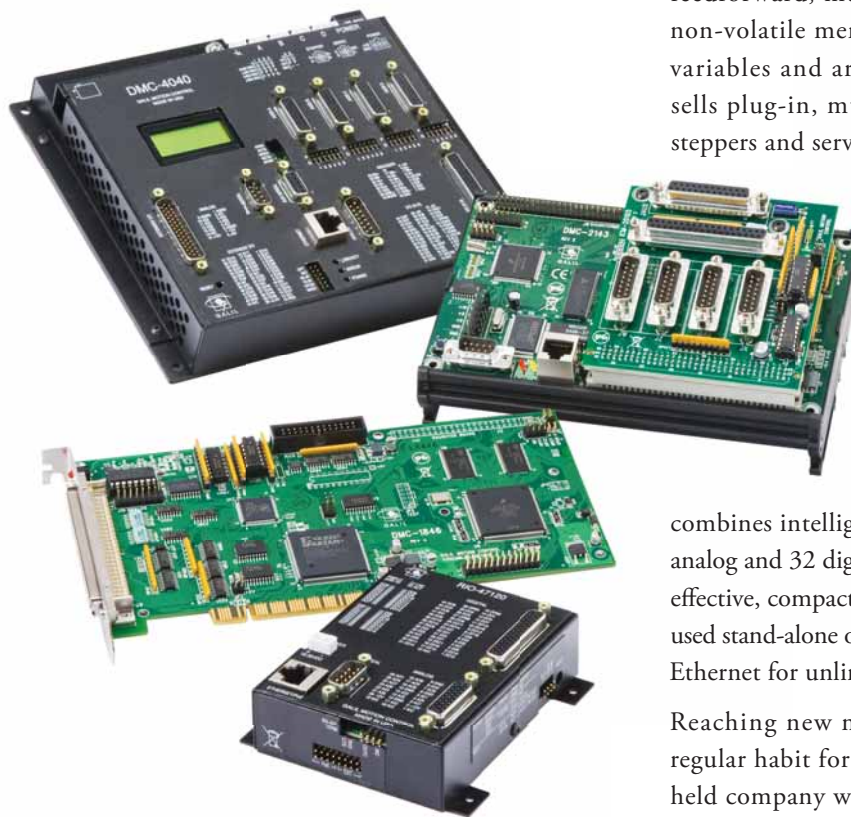
Galil recently celebrated the 25th anniversary of the shipment of their first motion controller. On July 5, 1983 Galil shipped the DMC-100 which was the first microprocessor-based servo motion controller using solely digital control that did not require tachometer feedback. Since the introduction of their first servo motion controller, Galil has continued to

break new ground in motion control, having gone on to deliver over 500,000 motion controllers worldwide. Galil is currently shipping their 5th generation motion controllers- the Accelera Series which provide ultra high-speed and precision. Features include multi-axis coordinated motion, advanced PID with velocity and acceleration feedforward, multitasking, and non-volatile memory for programs, variables and arrays. Galil also sells plug-in, multi-axis drives for steppers and servos which save money, space and wiring.

Galil has recently expanded into the I/O market with the introduction of its new RIO-471x0 Pocket PLC. This new product

combines intelligence along with 16 analog and 32 digital I/O in a cost-effective, compact package. It can be used stand-alone or connected to the Ethernet for unlimited I/O expansion.

Reaching new milestones is a regular habit for Galil, a privately held company which has achieved profitability for over 94 consecutive quarters. ■



Galil's current line of motion controllers includes the DMC-40x0 Accelera Ethernet/RS232 controllers, DMC-18x6 Accelera PCI controllers, DMC-21x3 Econo Ethernet/RS232 controllers and RIO-471x0 Pocket PLC.



# Galil. We Move the World.

With over 500,000 controllers installed worldwide, Galil is the #1 leading supplier of motion controllers. Galil's legacy of innovation began in 1983 when they introduced the first microprocessor-based servo motion controller. Today, Galil continues its leadership by offering the most powerful, cost-effective and easy-to-use motion controllers to accommodate all your motion needs.

Galil provides you with the widest choice of single or multi-axis, bus-based or stand-alone, and box-level or card-level controllers. Interface options include PCI, ISA, PC/104, cPCI, USB, RS232 and Ethernet. Select from 1-, 2-, 3-, 4-, 5-, 6-, 7- and 8-axis controllers, and configure them to run stepper or servo motors on any combination of axes.

Additionally, Galil provides various accessories that enable you to complete your project quickly. These include I/O controllers, servo motors, amplifiers and software tools for quick set-up and "one-button" servo tuning. ■

## Rely on Galil for Unmatched Support and Service

With every Galil controller you own, you also get the industry's most skilled team of motion specialists as well as an impressive array of online support tools.

Galil's motion specialists have over 100 man-years of experience, and they stand ready to specifically address your application. You can reach them today at 800-377-6329. ■

### ACCELERA CONTROLLERS

<b>DMC-40x0</b>	Ethernet/RS232, 1-8 axes
<b>DMC-18x6</b>	PCI, 1-8 axes
<b>RIO-471x0</b>	Pocket PLC

### ECONO CONTROLLERS

<b>DMC-21x3</b>	Ethernet/RS232, 1-8 axes
<b>DMC-18x2</b>	PCI, 1-4 axes
<b>CDS-3310</b>	Ethernet/RS232, 1 axis with drive
<b>DMC-14x5</b>	Ethernet/RS232, 1-2 axis
<b>DMC-1417</b>	PCI, 1 axis
<b>IOC-7007</b>	Ethernet I/O Controller

### OTHER MOTION CONTROLLERS

<b>DMC-12x0</b>	PC/104, 1-8 axes
<b>DMC-16x0</b>	cPCI, 1-4 axes
<b>DMC-17x0</b>	ISA, 1-8 axes
<b>DMC-2xx0</b>	USB, Ethernet/RS232, 1-8 axes
<b>DMC-1410</b>	ISA, 1 axis
<b>DMC-1411</b>	PC/104, 1 axis
<b>DMC-1412</b>	RS232, 1 axis

### PLUG-IN, MULTI-AXIS DRIVES (40X0)

<b>AMP-430x0.</b>	2 & 4 axis, 500W servo drives
<b>AMP-43140.</b>	4 axis, 20W servo drives
<b>SDM-44040.</b>	4 axis, full/half stepper drives
<b>SDM-44140.</b>	4 axis, microstep drives

### PLUG-IN, MULTI-AXIS DRIVES (21X3)

<b>AMP-20341.</b>	4 axis, 20W servo drives
<b>AMP-204x0.</b>	2 & 4 axis, 200W servo drives
<b>AMP-205x0.</b>	2 & 4 axis, 500W servo drives
<b>SDM-20242.</b>	4 axis, full/half stepper drives
<b>SDM-206x0.</b>	2 & 4 axis, microstep drives

### SOFTWARE TOOLS

**Communication Drivers.** For DOS, QNX, Linux and all current versions of Windows

**SmartTerm.** Provides a friendly interface to all Galil controllers

**GalilTools.** Servo Tuning and analysis software

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

**ActiveX Toolkit.** Custom controls for Visual Basic or other ActiveX software

**CAD-to-DMC.** Translates AutoCAD DXF files into DMC controller files

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✓	MotionCode™ Toolkit, step-by-step solutions with downloadable code <a href="http://www.galilmc.com/support/motioncode/index.html">http://www.galilmc.com/support/motioncode/index.html</a>
✓	MotorSizer™ Tool for quick sizing of stepper and servo motion systems <a href="http://www.galilmc.com/support/motorsizer/index.html">http://www.galilmc.com/support/motorsizer/index.html</a>
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