High Performance Speed Control for Optical and Laser Scanning Applications

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Introduction

Rotating optical and laser scanning systems usually require that the optical element or active E/O payload maintain a high level of speed stability during operation. This is necessary since most rotary scanning applications rely on a constant angular rate being generated by the scan motor in order to produce proper output from the system. Speed errors, both repetitive and random, result in a geometric distortion or noise in an imaging system, and measurement errors in positioning systems.

This article describes high performance speed control systems and scan motors, such as those available from SignalTronix, and shows a few application examples.

DC Brushless Motor Control

The velocity control of a brushless DC motor is essentially identical to standard DC brush motor control in that the brushless motor speed is a function of applied motor voltage. The principles of velocity or position feedback are utilized in a similar fashion and are depicted in Figure 1. The elements within the closed-loop block diagram are essentially the same for both motor types, with the exception of additional motor commutation functions which are built into the power amplifier in the brushless motor case.

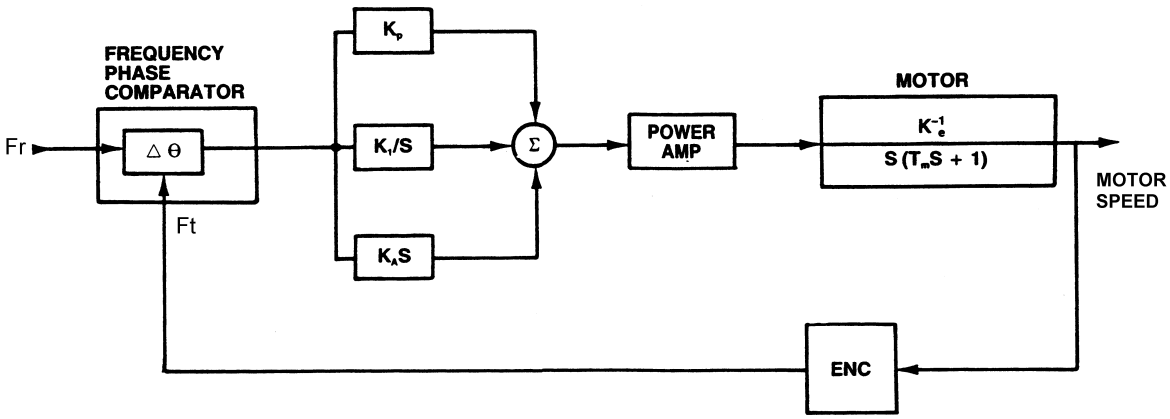

Figure 1. Speed control system block diagram, brushless DC motor.

The DC brushless motor transfer function is shown in detail in Figure 2. For simplification purposes, the commutation and pulse-width modulation circuits have been omitted.

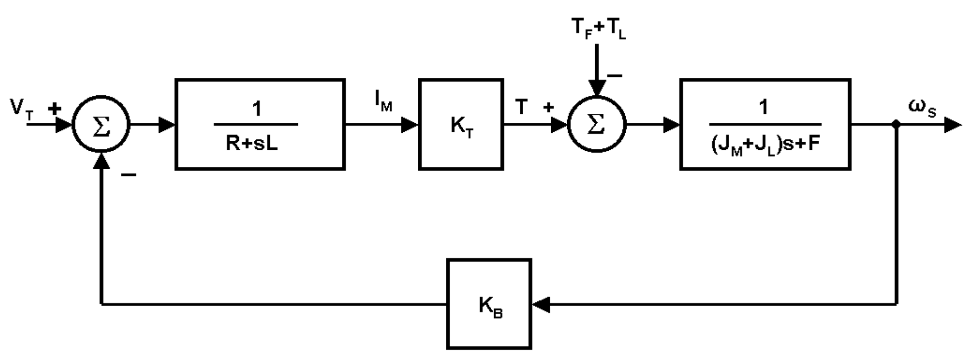

Figure 2. DC motor transfer function block diagram.

To implement the exceptional speed regulation features of phase lock control, the shaft frequency and phase position are measured with a shaft-mounted incremental encoder. The encoder pulses are frequency and phase compared with the reference frequency using a frequency/phase comparator, which has the transfer characteristics as shown in Figure 3. The frequency/phase comparator has a unique transfer characteristic which allows the device to produce an output which is in saturation until the two input frequencies are equal. The saturation level is either positive or negative in value, and is useful in determining whether the motor speed is too high or too low.

The controller will accelerate or decelerate the motor until there is no frequency difference between the reference and the encoder signal. At this point a phase measurement is made by the comparator with every reference pulse cycle and an output voltage is generated which is proportional to the phase error. Very high speed control loop gain may be achieved by this method, and as a result, exceptional speed stability and no long term speed error are the main advantages. The phase error signal is then processed through a PID controller and compensator, similar to that used in a conventional brush DC motor control system.

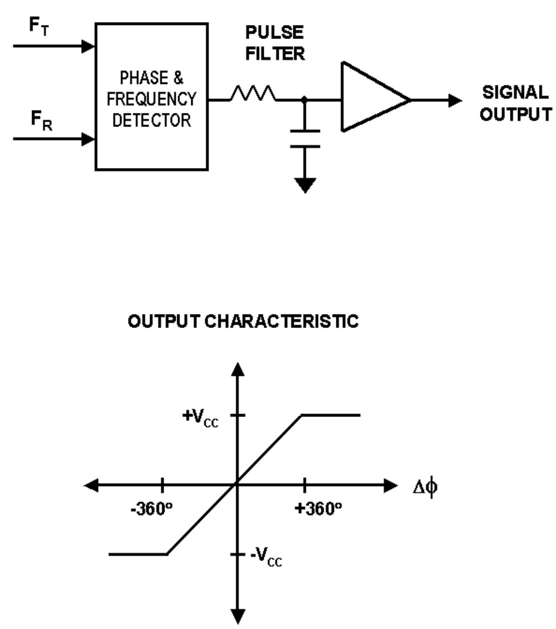

Figure 3. Phase/frequency detector characteristics.

The detailed DC motor transfer function shown in figure 2 relates the motor angular velocity ω_s to the applied terminal voltage V_T. In English units, the constants are defined as: (Across any two leads for a three phase delta, or three phase Y motor).

R = Motor winding resistance (Ohms)

L = Motor inductance (Henry)

I_M = Motor current (Amperes)

K_T = Motor torque sensitivity (oz-in/Amp)

K_B = Motor back-EMF constant (Volts/radian/second)

J_M = Motor moment of inertia (oz-in/second^2)

J_L = Load moment of inertia (oz-in/second^2)

$T_F + T_L$ = Sum of the friction and load torque (oz-in)

F = Motor damping coefficient

As the control system is activated, the error signal is amplified and converted to motor current, causing the motor to accelerate to a speed at which f_T exceeds (overshoots) f_R. At this point, the error signal reverses polarity, reducing the motor speed until f_T equals f_R. Ultimately, a point of equilibrium is reached at which time the frequency/phase comparator error voltage is zero, and the integrator output voltage regulates the speed of the motor. Furthermore, the high DC gain of the integrator maintains a zero phase difference between f_T and f_R resulting in edge lock synchronization.

To insure stable and accurate speed control, and to determine the gain coefficients K_P, K_I and K_A, the motor and load characteristics should be modeled. Several very useful simulation programs such as SIMULINK are available for the systems designer which greatly reduce development time by allowing the rapid testing of various control configurations.

APPLICATION EXAMPLES

The following sections describe a few of the many scanner designs and control systems which have been developed over the last few years. The overall industry trend reflects the continuing drive of the market to improve performance, reduce power consumption and size of the supporting electronics, and to reduce the cost of the scanner subsystem.

Fortunately, the consumer electronics and automotive markets have provided many of the electronic components which have proven to be invaluable in the quest to reduce the size and cost of the scanning system. Progress in miniaturization and power reduction of the scanner control electronics is also largely due to the advancements in brushless DC motor driver technology. As the cost and complexity of the drive electronics for brushless motors approaches that of conventional DC motors, brushless motor technology will likely displace all other motor types in scanning subsystems, as it offers high efficiency along with the high reliability previously found only in AC motors.

Application Example: Thermal Imager Scanner

Pictured in Figure 4 is a small eight facet polygon scanner which is designed for a vehicle mounted thermal (IR) camera system. This compact ball bearing scanner operates at 450 RPM and serves to generate an image in conjunction with an infrared detector array. The motor and control system is designed to maintain polygon speed regulation to within 15 PPM (0.0015%). In addition, the control system must maintain the specified speed regulation in the presence of base disturbances which are passed to the scanner as a result of vehicle motion. These challenges have been met in this compact scanner by the use of a high resolution encoder and lightweight polygon design in conjunction with a responsive control system.

The scanner employs a small low voltage brushless DC motor which is optimized for low cogging torque and smooth operation at low speed. Motor commutation is derived from three dedicated commutation tracks on the optical encoder disk which also includes a high resolution 3000 line count tachometer track as well as an index.

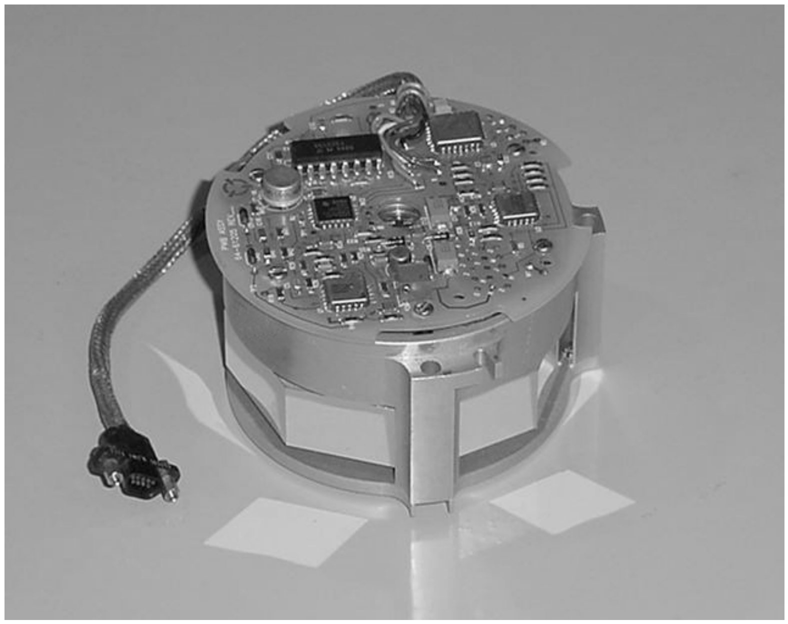

Figure 4. Thermal imager scanner.

At the center of the control system is a single chip motor driver which decodes the commutation information provided by the encoder and produces the correct three phase motor current waveforms necessary for proper operation of the motor. Motor driver IC's of this type are commonplace devices found in computer disk drive and CD player applications. The motor driver produces a current through the motor windings which is proportional to a command voltage at it's input and also incorporates a brake feature which is used to decelerate the motor for better control of the polygon speed under the influence of disturbances.

Tight speed control is accomplished by the use of a phase-lock loop regulation method as described in detail previously. At the operating speed of 450RPM, the 3000 line optical encoder produces a tachometer frequency of 22.5KHz, which is compared against an externally generated reference frequency in the phase/frequency comparator circuit.   Any resulting phase error voltage is amplified and filtered, and then fed to the motor driver which increases or reduces the motor current to maintain the speed and minimize the phase error. If the motor control voltage falls below a predetermined level indicating that the scanner is operating above the reference speed then the control system applies dynamic braking to the motor which quickly decelerates the motor and the polygon. A block diagram of the controller/driver is shown in Figure 5.

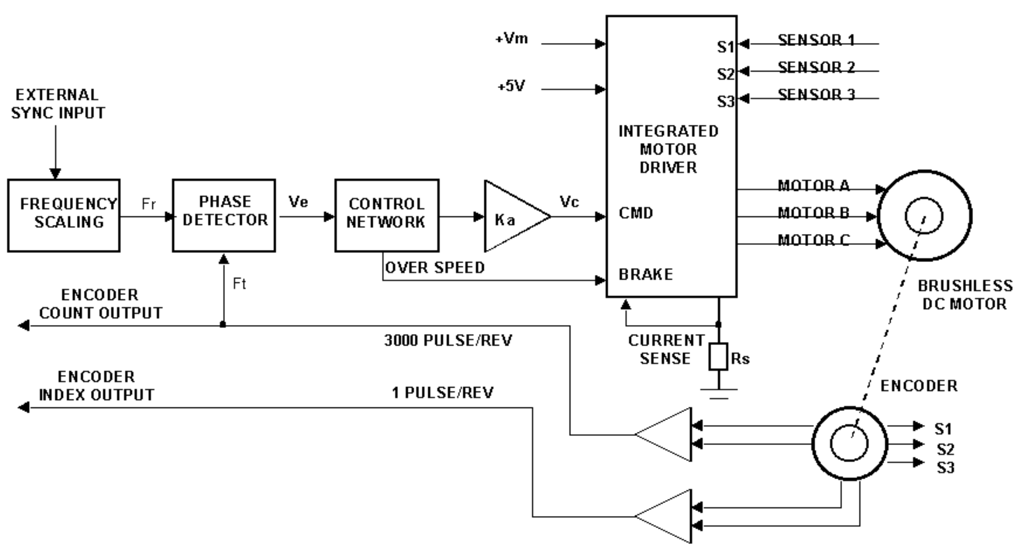

Figure 5. IR scanner controller/driver.

High Speed Single Faceted Scanner

The successful scanner design shown in Figure 6 was developed for the publishing and printing industry for use in image setting machines, which are essentially large laser printers. After a page is composed and edited on a computer, the image setter usually prints four or more pages on one sheet of film. The film is then used to transfer the images to printing plates and ultimately to paper. To record the image on film, a single faceted mirror, or "monogon", rotates at high speed and scans an intensity modulated laser spot along the length of the film. The film sheet usually lies on the inside surface of a cylindrical drum, although flat plate recording systems which use an f-θ lens have also been designed. Also, the film sheet is stationary while the scanner rides the length of the drum on precision linear bearings driven by a ball-screw mechanism.

For the ultimate in speed stability and cross scan accuracy, as well as greatly improved bearing life, the scanner rotating elements may be supported by self pumping conical air bearings. This type of bearing provides excellent high speed stability and low friction with the benefit of virtually unlimited operating life. The self pumping action of the air bearing design is a major factor in reducing the cost of the scanner since an external air supply is not required. Some versions of this type of scanner operate at 60,000 RPM. Nevertheless, air bearing scanners are significantly more expensive than the ball bearing versions and are usually cost prohibitive in many applications. The scanner and control system block diagram is shown in Figure 7.

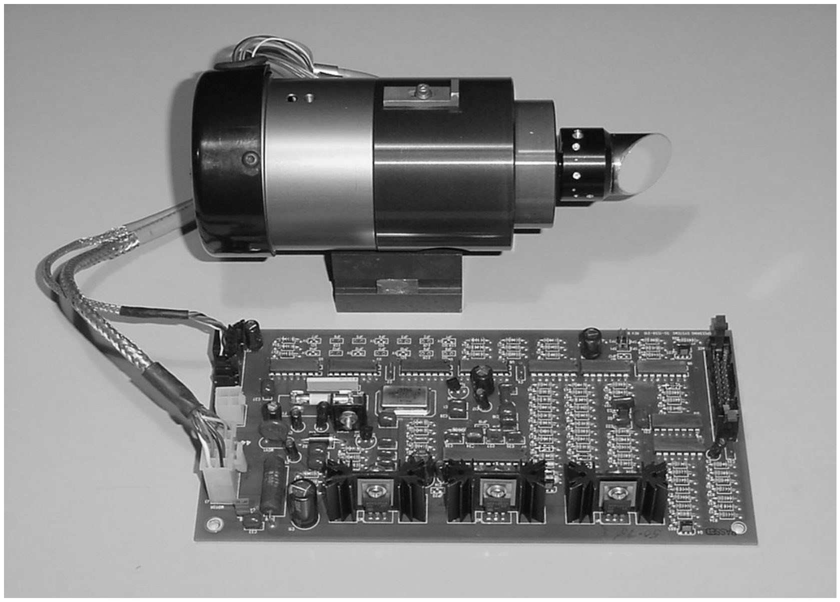

Figure 6. High speed scanner and controller/driver.

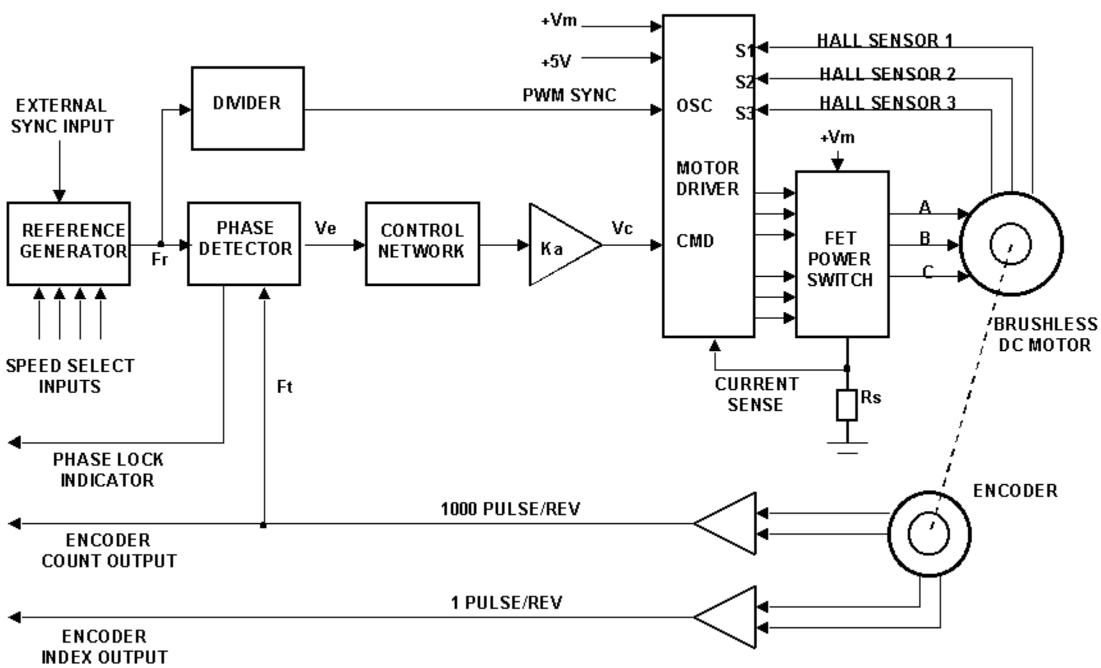

Figure 7. High speed scanner and controller functional diagram.