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SERVO**STAR**® S- and CD-series Sine Encoder Feedback

The SERVO**STAR** S and SERVO**STAR** CD family of drives offers the ability to accept signals from various feedback devices. Sine Encoders provide analog-encoded motor position data to the drive amplifier. The advantage of these analog signals is that they can be resolved to extremely small intervals, providing a lot of data about the motor shaft position while maintaining reasonable data transmission rates. The disadvantage is that analog signals are notably susceptible to noise pickup and require good wiring installation practices. A multi-turn absolute position option is available to eliminate the need for machine homing after power up.

Application Details

Sine encoders offer advantages over standard Digital encoders. Because the output signal is a continuous sinusoidal waveform, the drive electronics is able to break down each cycle into many sub parts (or counts). This increases the system's ability to position within smaller increments. More importantly, but not as obvious, is the increased data flowing into the velocity loop compensator, allowing increased system gains (to overcome large load inertia) while controlling current hash noise. Much greater system stiffness can be achieved.

Resolution

Sine encoders provide two incremental sinusoidal signals (A and B) with a phase shift of 90°. Because they are differential, the complementary channels (A and Not A - B and Not B) combine to create a 1-volt peak-to-peak signal to the control electronics with good noise immunity. Because the signals are separated by 90 degrees (quadrature encoded), the receiving electronics (quadrature decode) is capable of multiplying the fundamental resolution by a factor of four. Through a method called interpolation, the SERVO**STAR** breaks down the sine wave into an additional 256 parts. For every sinus encoder cycle (corresponding to one line count), the SERVO**STAR** sine encoder cycle provides up to 1024 extra internal counts.

For example, if a sine encoder specifies a resolution of 2048 lines per revolution, its actual controllable resolution per mechanical revolution becomes a maximum of 2,097,152 (2048 x 4 x 256) counts. The SERVO**STAR** drive uses this increased feedback resolution in both the velocity loop and the position loop controls. Increased resolution in the velocity loop helps to reduce truncation and quantitization errors for reduced noise, resulting in the ability to achieve higher loop gains (required for large inertial loads), improved stiffness, and command smother current (reduced system noise). The increased resolution in the position loop gives the user increased repeatability and the ability to use higher loop gains with less noise.

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Theory of Operation

The incoming sine signals from the encoder are complementary presenting a single-ended signal waveform of 500 mVp-p riding on a 2.5 VDC carrier for each signal (see Figure 1). When these signals are presented to a differential receiver the resulting waveform is 1 V peak-to-peak riding on 0 VDC. These signals are sampled with analog-to-digital converters every 1.6 µs. The resultant digital words are handled with digital electronics (FPGA) providing arithmetic processing to decode the interpolated position. The resulting position word is fed to internal capture registers, for use in the control algorithms and to an accumulator that outputs the Encoder Equivalent output signal for the user. There is a limit to the amount of position change that is allowed in each 1.6 µs that establishes the 125 kHz input frequency limit.

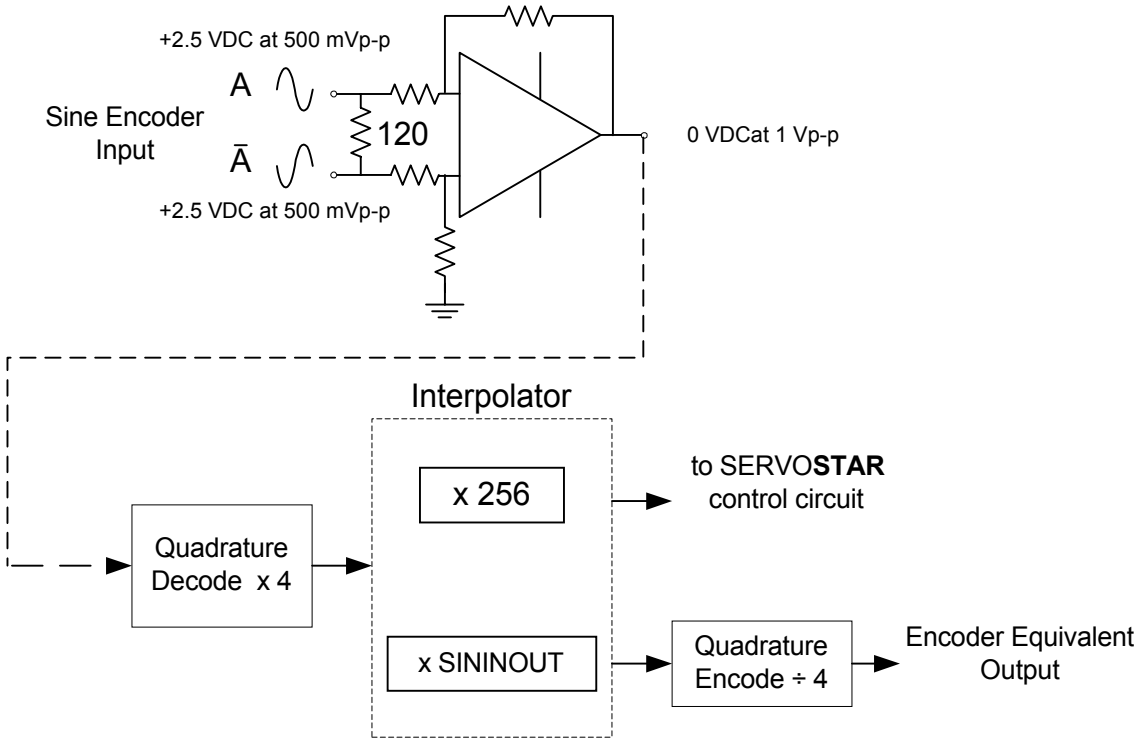


Figure 1: Equivalent Circuit and Diagram

The x256 box shown in the diagram can actually be made to a lesser multiply, if required, by the user by adjusting the MSININT variable (See EnDat™, below).

The encoder equivalent output is scaled according to the SININTOUT variable to allow reduction in the output resolution to keep the output frequency within limits after considering maximum system speed. The encoder equivalent output circuit immediately begins to reduce the accumulator value by outputting pulses, while limiting the maximum frequency to 2.5 MHz or less (depending on the value MSINFRQ). Systems like this inherently distort the encoder output quadrate encoding. If the accumulator gets more than 1 count per 1.6 µs, it outputs the signals at 2.5 MHz, which can distort the 90° edge separation. This is normally not a problem, but is worth noting and another reason to keep the design limit to 1.25 MHz.

Some receiver circuits in user controllers have digital filtering that attempt to discriminate the small edge separation as noise, resulting in pulse loss. The FPGA has a small accumulator to allow for pulse storage beyond the 2.5 MHz. If this buffer overflows, an error is generated and encoder equivalent pulses from the output port are lost.

Accuracy

The system accuracy is a direct function of the accuracy of the sine encoder. Typical values range are ± 20 and ± 60 arc-seconds. The on-board electronic decoder adds another 1% of one sine wave period to the total system error. For example, using a 2048 line encoder rated for 20 arc-seconds accuracy, the electronics adds another 6.5 arc-seconds of inaccuracy for a total of ±26.5 arc-seconds.

Types of Sine Encoders

Since all encoder signals are incremental, some method of providing information about the motor's position at power-up time is required. Different methods for accomplishing this exist in different encoder types. In its crudest form, a power-up poling sequence can be used. This requires motor motion and is subject to commutation errors and limits on stiction and inertia. While the SERVO**STAR** does support this method, it is not recommended. More information is contained in the VarCom document.

The SERVO**STAR** is able to receive many types of auxiliary signals from many different types of encoders for this power-up position information. These auxiliary signals give the SERVO**STAR** information to begin commutation at power-up:

Incremental with Hall Effect Sensors

Hall channels provide coarse information about the motor position and are used only at power-up to determine enough information to begin motor commutation. More information can be found about this type of operation in the *SERVO**STAR** S and CD User Manual*. A description of use with and without marker channels is described (MENCTYPES 0 and 6). There are no anomalies to this operation when using a sine encoder.

Incremental with C&D lines

C & D channels reference sine encoders that provide an auxiliary commutation track. They are typically two channels equivalent to the A and B channels, but have only one sine wave per mechanical revolution. The SERVO**STAR** uses the same interpolation method on these channels to provide commutation information at power-up to 1 part in 1024. The SERVO**STAR** performs this operation automatically. Support is provided for systems using a marker channel (MENCTYPE 7) and systems not using a marker channel (MENCTYPE 8). The information in the *SERVO**STAR**® S and CD User Manual* provides data on use with a marker channel and the MENCOFF variable. The actual hardware read position of these signals is returned by the HWPOS command, used while the drive is in ZERO mode (see ZERO). The variable MPHASE is available as a software offset for these channels.

Incremental with EnDat

EnDat is a trademark of Heidenhain Corporation and refers to a method of serial communication to several of their encoder product offerings associated with absolute position encoders. These devices "remember" where they are through power cycle. The SERVO**STAR** uses the EnDat (MENCTYPE 9) communication channel to automatically query power-up position from the encoder. These encoders have internal non-volatile memory used by the drive to store offset values. The HSAVE command causes the MPHASE, ZPOS, and PFBOFF variables to be saved in the encoder. The memory is read back at power-up or during a LOAD command execution. The command, HWPOS, is provided to allow querying of the encoder's absolute position (not interpolated) directly from the encoder as defined by Heidenhain's EnDAT specification. PFBOFF allows the user to conveniently offset a machine home (or zero).

The multi-turn versions of EnDat encoders are capable of "knowing" where they are out to 4096 revolutions (12 bit). Some versions have 2048 sine wave, when decoded, providing 21-bit resolution. The total result is 33 bits of data. The SERVO**STAR* **position loop operates on 32 bit signed data. For systems using full turns data from the encoder, system resolution must be reduced using the MSININT variable set to 128 or 64 (depending on the use of the sign bit of the 32 bit position word).

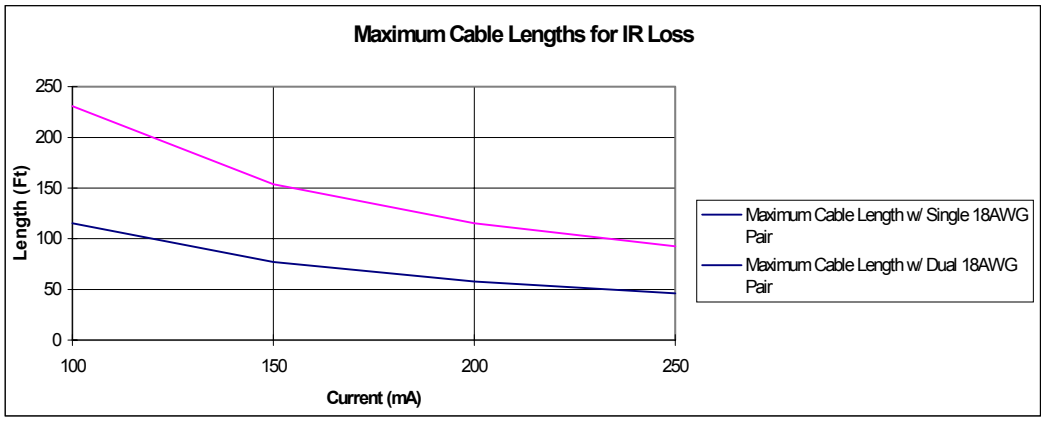
MSININT=256	***32***	***31 …… 0***	*Word Justification for Maximum Resolution*
MSININT=128		***32 …… 1***	***0*** *Justification for Max Turns -Bi directional*
MSININT=64		***± 32 …… 2***	***1 0*** *Justification for Max Turns -Unidirectional*

EnDat Encoders do not have an index pulse integral to the encoder but systems often require an index pulse for an accurate homing process, especially when applying a single turn EnDat encoder to a multi turn system. An index pulse is created by the SERVO**STAR** drive for the encoder equivalent output port by doing a position compare, modulo "Encoder Equivalent Output counts per revolution". The compare value is programmable via the ZPOS variable stored in encoder memory. This feature is available only with MENCTYPE=9 (EnDat Encoders). The system reads the EnDat absolute position, adds the sine interpolated value adjusted by MSININT, and adjusts to SININTOUT units and uses this value as the initial value for the encoder equivalent output as the reference compared to the user's programmable ZPOS variable. When the two are equal, an index pulse is output. The user can adjust the actual physical location of the index pulse by varying the ZPOS parameter. Range checking of the ZPOS parameter is not done, so the user must enter a reasonable value (negative numbers are allowed). The ZPOS variable can be changed on-the-fly. The actual functional range is 0 to MENCRES*MSININTOUT, units are "Encoder Output Lines," and the default value is 0. The pulse width of the marker is 90° of the Encoder Equivalent Output pulse signal.

The ENCOUT value has no effect on this function. While ENCOUT may be changed, the marker pulse width is unaffected.

Cable Limitations

The Sine Encoder transmits analog signals of 1-volt peak-to-peak to the SERVO**STAR** drive. These signals are subject to noise induction if not carefully installed. Cables must have twisted pairs with an overall shield. The shields should be tied to earth at both ends of the cable. The cable should be routed in a "clean" conduit free of motor armature cables and other noise sources. As with any feedback device, cable capacitance should be kept low – no more than 47 pF per foot. IR loss, total capacitance, and noise susceptibility largely limit cable lengths. It is best to keep these cables short (less than 50 ft.). Actual wire gage requirements are driven by the IR loss of the power supply, which should be no smaller than 18 AWG. Power supply tolerance must be considered in the voltage loss calculations.



Encoder Equivalent Output

The Encoder Equivalent Output (supplied by the SERVO**STAR** drive) is converted from sinus signals to incremental pulses. The SININTOUT and ENCOUT variables can adjust the resolution of the encoder equivalent output. The value is determined by the read- only variable, ENCOUT. ENCOUT is determined by:

ENCOUT = MENCRES * SININTOUT / ENCOUTO

Recognizing that users will attach the encoder output port to equipment incapable of receiving such high data rates, an error detection system is provided. The MSINFRQ variable can be set to fault the system should the drive be required to send out pulses higher than the limit set by this variable. This variable can also be set to ignore overflows, but be careful, as pulses may be lost.

Frequency Limitations

The sinus inputs to the SERVO**STAR** must not exceed 125 kHz. The encoder equivalent output to the user is limited to 2.5 MHz (quadrature encoded – or 10 MHz data rate), but the user should limit it to a design maximum of 1.25 MHz to allow for overshoot. The following table shows the recommended speed / output frequency limitations that should be used for design.

	SININTOUT Setting (EEO Resolution - Lines per Rev)			
Encoder Resolution	128	64	32	16
512 Sine Wave per Rev	1140 rpm Max 65,536 LPR	2285 rpm 32,768 LPR	4575 rpm 16,384 LPR	9150 rpm 8,192 LPR
2048 Sine Wave per Rev	280 rpm Max 262,144 LPR	570 rpm 131,072 LPR	1140 rpm 65,536 LPR	2,288 rpm 32,768 LPR

Table 1: Maximum Design Speeds vs. Maximum EEO Resolution for 1.25MHz Limit

Encoder Alignment

Danaher Motion motors with integral encoders are factory-aligned and require no adjustments. Systems using encoders mounted by the customer may have the encoder aligned electrically. If so, the drive contains no motor-specific variables regarding encoder alignment. This allows each drive from machine-to-machine to have the same parameter set. Alignment may also be done through the software variables, MPHASE and MENCOFF.

System Fault Codes

The SERVO**STAR** is capable of detecting errors within the system and displaying a fault status on its 7-segment display:

r3: **Sine Encoder Init Fail: Error 4.3**: This code means a hardware problem internal to the drive has been detected. The system requires factory repair.

r7: **C/D Line Break: Error 4.7**: This code means the C and D channel decode is invalid. See **r8** for further details.

r8: **A/B Out of Range: Error 4.8**: This code means the A- and B-channels have fallen out of the specified range of a minimum 0.5 volts (minimum peak-to-peak) and 1.15 volts (maximum peak-to-peak). This can be the result of a loss of a single channel, loss of a single differential line, signal degradation, excessive DC Offset, or excessive phase shift in one channel. Theoretically, a scope plot with the A-channel on the x-axis and the B-channel on the y-axis produces a circle with a radius of 0.5 volts (1/2 the peak-to-peak voltage). Any portion of this circle collapsing less than 0.25 volts causes this error.

r9: **Burst Overflow: Error 4.9**: This code means the Encoder Equivalent Output accumulator has overflowed and pulses are lost. It is possible to change the action of this fault using the MSINFRQ variable.

r10: **Endat Communication Fault**: This code means serial communication to the Endat Encoder has failed. The drive makes several attempts before aborting to this error.

Drive Connections

SERVOSTAR **C2 Connection**	**Sine Encoders with Marker and Open Collector Halls**	**Sine Encoder with Marker and C/D Channels**	**EnDat Encoders**
1	Sine High (A)	Sine High (A)	Sine High (A)
2	Sine Low (/A)	Sine Low (/A)	Sine Low (/A)
4	Cosine High (B)	Cosine High (B)	Cosine High (B)
5	Cosine Low (/B)	Cosine Low (/B)	Cosine Low (/B)
7	5V Supply Return (DC Com)	5V Supply Return (DC Com)	5V Supply Return (DC Com)
8	5V Supply Return (DC Com)	5V Supply Return (DC Com)	5V Supply Return (DC Com)
9	Hall 1 (A) Collector	C Channel Low (/C)	S Data -
10	Hall 2 (B) Collector	D Channel Low (/D)	S Clock -
11	Hall 3 (C) Collector		
13	Thermostat High	Thermostat High	Thermostat High
15	Marker High (I)	Marker High (I)	
16	Marker Low (/I)	Marker Low (/I)	
18	5 V Supply for Encoder + *	5 V Supply for Encoder +*	5 V Supply for Encoder (5 V)*
19	5 V Supply for Encoder +*	5 V Supply for Encoder +*	5 V Supply for Encoder (5 V)*
22	Must Connect to 5V (18-20)	C Channel High (C)	S Data +
23	Must Connect to 5V (18-20)	D Channel High (D)	S Clock +
24	Must Connect to 5V (18-20)		
25	Thermostat Low	Thermostat Low	Thermostat Low
Case or Frame	All Shields	All Shields	All Shields

Table 2: Drive Connections (*Several Power Supply Connections are Available)

Specifications: CB or SB Designator

Parameter	Units	Value	Comments
Maximum Input Frequency	Hz	125 k	Maximum Sinusoidal Input Frequency representing a maximum data rate of 128 MHz.
Nominal Single-ended Signal Amplitude	volt peak-to-peak	0.5 per signal	1-Volt Differential
Nominal DC Offset per Channel	VDC	2.5	
Minimum Differential Input Voltage	V	0.5	An A/B Out Of Range Fault occurs when the input falls below this value.
Maximum Differential Input Voltage	V	1.15	Analog amplifiers begin to clip, causing read inaccuracies.
Absolute Maximum Differential Input Voltage	V	1.2	A voltage at any input channel (with respect to DC Common) causes the drive to detect a broken wire.
Maximum Input Interpolation Factor	Count	256x + 4x Sinus period	The internal counts of the drive is 1024 * Sine periods per revolution.
Maximum Encoder Equivalent Output Interpolation Factor	Lines	128x	Encoder Equivalent Output Signal is Incremental Pulses.
Maximum Encoder Equivalent Output Frequency	MHz	2.5	Designed to 1.25 MHz to allow sufficient room for overshoot. MSINFRQ can be set to trigger a “Burst Overflow” fault if this value is exceeded.
Maximum Encoder Equivalent Output Data Rate	MHz	10	Quadrature Encoded Pulses equate to 4x data rate at receiver electronics.
Minimum Edge Separation of Encoder Equivalent Output Channel	ns	100, 200, 400, 800	Selectable with MSINFRQ (± 10%)
Relative Accuracy	Electrical Degrees	± 3.5	Interpolation Accuracy of one Sine Wave Cycle or ±1 percent.
Encoder Supply Voltage	V	5 ± 2% 250 mA Max	SERVO**STAR** Supply to Encoder
Differential Input Impedance	Ohms	120	

EnDat is a registered trade name of Heidenhain Corporation.

Some encoder manufactures output C and D channels with 1 V peak-to-peak signals referenced to a 2.5 VDC offset instead of 2 500 mV differential channels. These signals are acceptable to the SERVO*STAR *as the receiver electronics still decode this differential signal as a 1V peak-to-peak waveform.

References

Please refer to the *SERVO**STAR** S and CD Setup and Reference Guide* for current syntax and related information on the variables and commands.

VER	MSININT	SININTOUT	MENCTYPE
MENCRES	MSINFRQ	MENCOFF	MPHASE
ENCOUT	ENCOUTO	PFBOFF	HWPOS
ZPOS	HSAVE	ZERO	