Position Transducer Integration Procedure

for the

Acutrol3000 Motion Control System

Technical Manual

TM-9377B

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Table of Contents

1.0 Introduction

1.1 Ratiometric Encoding System

The position encoding section of the Acutrol3000 instrumentation has a modular architecture providing flexibility to accommodate various measurement transducers and encoding objectives. The front end consists of four Feedback Channel blocks, which accept either DC or 10 kHz AC carrier based signals. AC signals are demodulated, calibration constants for measurement and sensor errors are applied, and four scaled feedback variables are produced. The Ratio-metric Encoding block inputs these sine and cosine feedback signals and converts them to raw coarse and fine position measurements. Conditioner blocks provide control of scale, offset, and sense to accommodate system and user needs. Dual Speed Correlation Modules combine coarse/fine (reference/measurement) variables to produce a coherent composite position measurement. Finally, Look-up Tables provide a means to model and remove systematic errors.

1.2 Encoding System Structure

The Encoder Block Diagram (appended at the end of this document) shows the signal processing flow for a standard coarse/fine transducer configuration. The blocks are executed in the order that they are connected so that all data are current; the exact topology and corresponding function of the encoding system is determined by the input variable selections for each of the modules. The Inductosyn/resolver sin/cosine feedback signals are demodulated and scaled in the Feedback Channel block. Axis Interface Module (AIM) calibration constants compensate for hardware errors of the AIM board and the user calibration parameters compensate for transducer, stator amp, and wiring errors. In the Ratio-metric Encoding block, the sine and cosine feedback signals for a transducer are first compensated for cross coupling and then converted to a raw position using the ARCTAN2 function.

The raw COARSE_ANGLE (x085) has a full scale range of 1 (revolution) and the raw FINE_ANGLE (x108) has a full scale range of 1 (fine cycle). The coarse position is processed through a Coarse Conditioner, which adds a <coarse_offset> to set the zero point and a <coarse_sense> parameter to invert the direction as required to match the direction of the fine sensor. This conditioner is use to establish the proper phase relationship between the coarse and fine transducer positions prior to correlation.

Note that there are two correlation blocks; the first (computed in time) is used to correlate the range extended coarse position with the COARSE_COND position (X207) or the error corrected LUT_COARSE_OUT (x240) position. The extended coarse position is generally the normalized position estimate POS_EST_NORM (x168); using this variable makes it possible to accumulate turns whenever the full-scale range **FS_Range** is set to multiple revolutions. Alternatively, another variable scaled in revolutions could be used to provide an absolute measure of turns. This could be as simple as inputting the logic value of a sector switch through an analog channel and using this scaled/offset value for correlation with the resolver.

The second correlator is used to processes either the coarse composite position COARSE_COND (x207) or the look-up table corrected position LUT_COARSE_OUT (x240) with the raw fine position FINE_ANG (x108). This produces a composite position COMP_POS (x084) which is scaled in revolutions, has the range of the extended coarse measurement and has the accuracy of the fine.

A Factory Conditioner applies the user scale factor **FS_pos**, which converts revolutions to engineering units. Typically, this scale factor is 360 deg/rev. A factory position offset <factory_pos_off> is used to set the zero reference per Acutronic convention, and the <factory_sense> is used to change the direction that produces an increasing position value also per Acutronic convention. The output position of the Factory Conditioner is the FACT_POS_FBK (x107) and is the position reference used for error correction look-up tables and 3-phase motor commutation.

A User Conditioner provides the customer a means of changing the position sense and relocating the zero position per their test convention. The output variable POS_FBK (x166) is the compensated position feedback and serves as the observed position for state estimation and closed loop control.

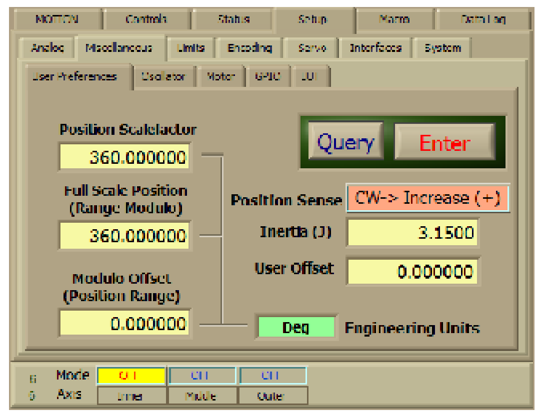
Caution: *The offset is applied before the change of sense; consequently, the sign of the offset required to set the position to zero will be counter-intuitive whenever the sense is inverting. The reason for this ordering is to allow changing the direction of rotation without requiring re-zeroing the table or reversing the sense of the offset.*

2.0 System Level Setup

This section discussed the hardware and software setup of the encoding features of the Acutrol3000. The most common configuration uses a 360 speed Inductosyn® as the fine position sensor and a 1 speed resolver as the coarse sensor. Examples will focus on this configuration, but other options are also addressed.

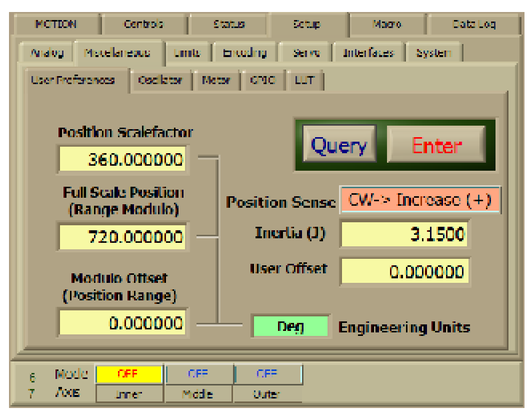
2.1 Position Scaling

The Position Scale Factor **pos_SF** is used to scale the motion variables (position, rate, and acceleration) independently for each axis**.** The native scaling of the encoded position is based on the absolute position range that can be measured by the position sensors. In the case of a rotary system the axis has an unambiguous range of one revolution. If a Position Scale Factor of 360 is defined, as is shown in the User Preferences panel, all motion variables will be scaled by a factor of 360 and position variables will have engineering units of degrees, rate variables will have units of degrees/sec, and acceleration will be scaled in deg/sec^2.



2.2 Position Range

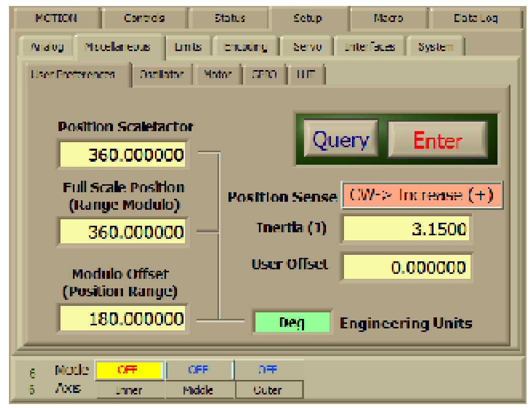
The Full Scale Position (range modulo) defines the numeric range that position variables can span and must be specified as an integer multiple of the base range. For a rotary system the base range is one revolution. In the User Preferences panel shown here, the Full Scale Position, scaled in user engineering units, is set to 720° (two revolutions). Accordingly, the position variables are constrained to the range of ±360°. A range of ±5 revolutions can be achieved by setting the Full Scale Position to 3600°. A Full Scale Position of 360° is the usual setting for a continuous rotation system and constrains values to ±180°. One last example;



the position values can be constrained to ±45° if the Full Scale Position is set to a range modulo of 90°. In this case all four quadrants are aliased to the same range (30°, 90°, -60°, and -150° are all encoded as 30°).

2.3 Unipolar Position Encoding

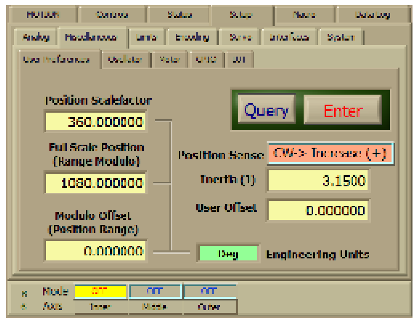
A Modulo Offset allows the operator to relocate the zero of the modulo range. Unipolar operation is achieved when the Offset Modulo is equal to one half of the Full Scale Position. In the User Preferences panel shown here, setting a value of 180° for the Modulo Offset would limit the value of position variables to be between 0 and 360°. It is important to note that it is the modulus that is offset, and not the actual position; consequently, the zero position is at the same physical location independent of the range or offset of the modulus. The Modulo Offset can be set at an arbitrary value such as 90° resulting in an operating range of -90° to +270°, not an unusual range for the Pitch axis of a multi-mode hydraulic flight simulator.

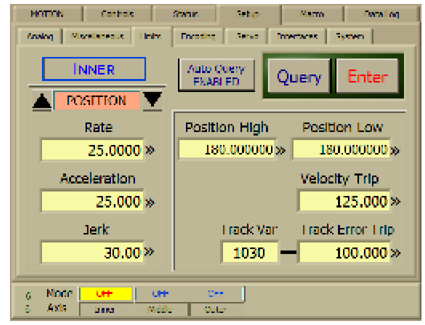


Note: *The settings that define the modulus behavior for the position measurement affect the position servo variables in the same manner.*

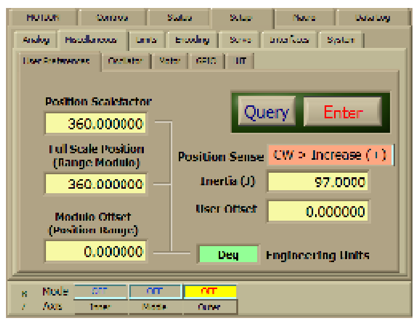
2.4 Continuous and Limited Range

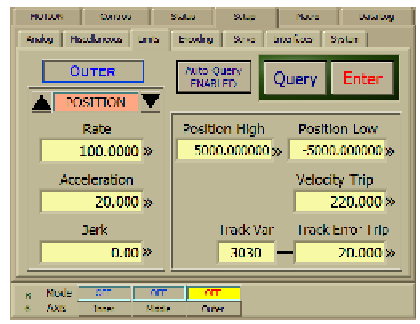
A rotary axis can be configured to operate continuously or it can be made to operate over a limited range. A linear axis is presumed to have a limited range. The Acutrol3000 has no specific operating modes to implement limited range of motion; rather, limited range is achieved by setting the Command Processor limits to values that are inside the bounds of the full-scale position range defined by the encoding system. If a system has physical stops that permit the travel to exceed the encoding range then unexpected behavior may result. For a limited rotation axis, it is always safer to set the full-scale range to several revolutions. Unless an over-center sector switch is employed, care must be taken to ensure that the encoding system is initialized with the axis in the base range of motion. The panels below are configured for a limited rotation system that has physical limits greater than ±180° and software limits set to ±180°. The position does not roll over at the 180° points and will properly servo out of a stop as long as the system was initialized in the correct revolution.





Whenever an axis is scaled for continuous operation, the Full Scale Position is set to the base range (usually one revolution). The position limits of the Command Processor must be set beyond the encoded position range.





Caution: *If the Command Processor limits are set too closet to the position range, the axis will inappropriately decelerate as it anticipates the near-by position limit. Higher rates, and lower acceleration limits aggravate this problem. For Continuous rotation, the CP position limits should be set well outside the range of* $\pm \boldsymbol{(FS\_Range + V^2_{max} / A_{lim})/2}$ *to avoid this condition.*

3.0 Hardware Setup

The hardware that is the subject of this section includes the Axis Interface Module (AIM), the Transition Panel in the Acutrol3000 chassis, the position transducers and corresponding motion system wiring, and the dual channel stator amplifier. This document does not attempt to describe the detailed operation of the hardware; but rather, the objective is to properly configure the hardware for specific encoding system configurations.

3.1 Transducer Drive Configuration

The AIM has two identical 10 kHz drive channels for exciting coarse and fine ratio-metric position transducers. The fine channel is generally configured in a current mode to drive the low impedance of an Inductosyn. In this mode the amplifier has a current gain of 50 mA/volt and a peak current of 500 mA. The coarse channel is generally configured in voltage mode and drives the relatively high impedance of a resolver. In voltage mode the drive amplifier has a gain of 1 v/v and a maximum output of 10 volts.

Jumpers for configuring the drive amplifiers on the AIM board are defined in the following table where the grayed columns represent the nominal configuration.

Fine Jumpers	Current Mode	Voltage Mode	Coarse Jumpers	Current Mode	Voltage Mode
JP5	AC	AC	**JP6**	AC	AC
JP4	In	Out	**JP1**	In	Out
JP2	Out	In	**JP3**	Out	In

In the Acutrol3000 chassis, the drive signals are output from the AIM on connector J8 and routed to the Transition module where they are rerouted and output on back panel connectors. These sub-D connectors have Acutrol ACT2000 compatible pin outs and are identified as Drive and Feedback connectors, J14, J24, and J34 for axis 1, 2, and 3 respectively. Test points are available for monitoring the drive signals and can be accessed by removing the config/test cover on the back of the Acutrol3000 chassis. The table below summarizes the signal connections and Transition panel test points:

		Pin Out		Test Points		
		AIM	Transition	Axis1	Axis2	Axis3
Inductosyn	Hi	FTD(+) Pin3	INDH Pin2	TP12	TP22	TP32
	Lo	FTD(-) Pin4	INDL Pin21	TP14	TP24	TP34
	Shield	AGND Pin 2	GND Pin20	--	--	--
Resolver	Hi	CTD(+) Pin6	CDRH Pin15	TP15	TP25	TP35
	Lo	CTD(-) Pin5	CDRL Pin 34	--	--	--
	Shield	AGND Pin7	GND Pin14	--	--	--

3.2 Transducer Feedback Configuration

Sine and Cosine signals are returned from the position transducers or Stator Amplifier to the Drive and Feedback connector (defined previously), then they are routed through the Transition Panel to the AIM board where they are buffered, filtered, and digitized. The conditioned AC signals can be monitored on test points and the corresponding demodulated variables can be displayed using the Operator Interface readout display. The following table summarizes the signal connections, test points, and variables for the fine channel (Inductosyn):

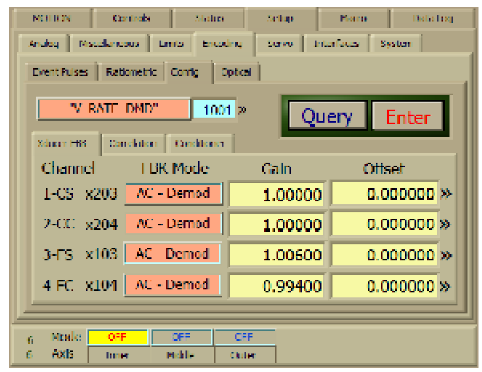
		Pin Out		Test Points		Disp Var
		AIM	Transition	Trans*	AIM	
Sine	Hi	FSF(+) Pin11	FSFBKH Pin7	TP11	TP22	X103
	Lo	FSF(-) Pin12	FSFBKL Pin26	TP21		
	Shield	AGND Pin 10	GND Pin25	TP31		
Cosine	Hi	FCF(+) Pin14	FCFBKH Pin9	TP13	TP21	X104
	Lo	FCF(-) Pin13	FCFBKH Pin28	TP23		
	Shield	AGND Pin15	GND Pin27	TP33		

* Transition panel test points are listed for axis 1, 2, and 3 respectively.

The following table summarizes the signal connections, test points, and variables for the coarse channel (resolver):

		Pin Out		Test Points		Disp
		AIM	Transition	Trans	AIM	Var
Sine	Hi	CSF(+) Pin17	CSFBKH Pin12	none	TP20	X203
	Lo	CSF(-) Pin19	CSFBKL Pin31			
	Shield	AGND Pin 16	GND Pin30			
Cosine	Hi	CCF(+) Pin20	CCFBKH Pin32	none	TP19	X204
	Lo	CCF(-) Pin19	CCFBKH Pin13			
	Shield	AGND Pin16	GND Pin14			

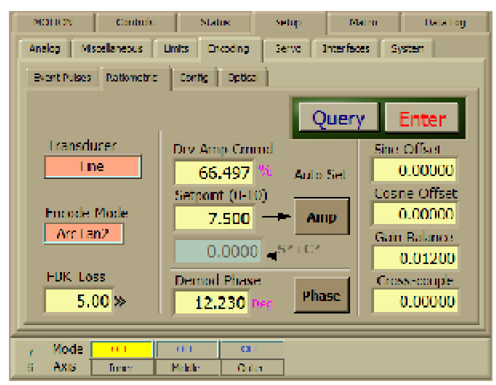
Ratiometric feedback signals are sine and cosine amplitude modulated as a function of position. AC carrier modulated signals must be demodulated before they can be used to generate position measurements. For all channels connected to AC transducers, select "AC-Demod" for the FBK Mode. For a first time initialization, the gains can be set to 1.0, and the offsets can be set to 0.0.



Some position sensors (such as analog optical encoders) produce static analog signals and do not require demodulation. For these channels, select "DC-Average" for the FBK Mode. If channels are not in use, then the FBK Mode should be "Disabled".

3.3 Verifying Proper Feedback Signals

This section presumes that the system position transducers are wired and the encoding system is ready for initial setup and test. The procedures that follow may also be used to trouble shoot a problem/ failure that arises at a later time.



The following procedure uses the Setup:Encoding:Ratiometric panel in the Graphical User Interface (GUI).

Step 1: Select the Coarse or Fine transducer.

Step 2: Select a Readout window to display the feedback magnitude Sqrt(S^2+C^2) for the corresponding sensor (x106 for fine and x206 for coarse).

Step 3: Enter a value of 7.5 for the *Drive Amp Set Point*.

Step 4: Set the *Drive Amp Cmmd* to 50%.

Step 5: Press and hold the *Auto Set Phase* button for 3 to 4 seconds and verify that the value of Sqrt(S^2+C^2) is greater than 1 and less than 10. If this is true then proceed to Step 6, other wise go to the Trouble Shooting Check List at the end of this section.

Step 6: Press and Hold the *Auto Set Amp* button for several seconds (at a time) and verify that the value of Sqrt(S^2+C^2) is approximately equal to the Set Point and that the Drv Amp Cmmd is between 30 and 95%. If this is true, then proceed to Step 7, other wise go to the **Trouble Shooting Check List** at the end of this section.

Step 7: If this is an Inductosyn setup, and the *Drv Amp Cmmd* is at the fringe of the range, then it might be advisable to change the Stator Amp gain by one increment. Adjust the Stator Amp gain in the direction that brings the magnitude closer to the center of the range and repeat the procedure starting at Step 5. In the case of a resolver, there is not much that can be done to change the feedback gain. A low value of Sqrt(S^2+C^2) is usually not a problem; under no circumstances should the *Drv Amp Cmmd* be set greater than 95%.

3.4 Trouble Shooting Check List

You are here because the Sqrt(S^2+C^2) feedback magnitude is either too large or too small.

A. If the feedback magnitude Sqrt(S^2+C^2) is saturated or small, but not zero, then try adjusting the stator amp gains by one step at a time to see if this brings the magnitude into an acceptable range. Adjust the Stator Amp gain (both channels must be set the same) and return to the procedure above starting at Step 5.

B. Note: some Inductosyn models have very low transformation ratios and require that the Stator Amp be configured with the 10X gain jumper installed.

C. If the magnitude Sqrt(S^2+C^2) is very nearly zero then there is a problem in either the drive or the feedback circuitry/wiring. Check that the transducer is being excited with a 10 kHz sine wave on the drive “Hi” test point identified in section 0 for the corresponding coarse/fine channel and axis. This signal is ideally in the range of 10 to 15 volts P-P and should show no signs of distortion.

D. If the drive is O.K. then verify that a related Stator Amp has ±12 volt power supplies and that there is an output on both channels of the Stator Amp. Note that the Inductosyn feedback signals can be monitored on test points at the back of the Acutrol3000 chassis.

E. If an Inductosyn drive has square waves on the drive “Hi” test point, then it is probably because the circuit is broken somewhere and there is no current feedback. Monitor the current feedback (voltage) on the drive “Lo” test point, this value will be zero if the circuit path is open. The sensitivity at this point is 1 A/V.

F. Verify that the feedback channels are properly configured (Demod/Ave) and that the Gains offsets are set as defined above.

4.0 Position Encoding

4.1 Fine Position Feedback

The fine (raw) position feedback (FINE_ANG x108) is a high accuracy position measurement which is unique over one fine cycle of the sensor. This variable is scaled with a range of ±0.5 corresponding to ±0.5 fine cycles and serves as measurement variable for coarse/fine correlation in its raw form. There is no provision for conditioning prior to correlation; consequently, the responsibility falls on the conditioning of the coarse sensor to ensure a proper coarse/fine relationship for correlation.

Verify Fine Feedback: Select variable FINE_ANG **x108** in a readout window and verify that it is encoding fine position. As the axis is rotated, verify that the feedback magnitude Sqrt(S^2+C^2) **x106** is fairly constant and close in value to the set point (7.5). If this is not the case, then check the demodulated feedback variables FINE_SINE **x103** and FINE_COS **x104** and verify that each signal is modulating ±7.5 volts as the axis is rotated and the period is approximately one fine cycle. Do not proceed until this condition is achieved.

Based on the factory-defined convention for axis rotation sense, make a note of the direction of the fine angle for future reference:

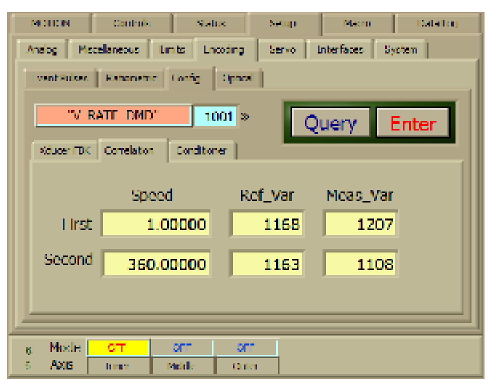
FINE Direction CW____ or CCW____.

Acutronic Convention for Axis Rotation: *The standard convention states that clock-wise rotation should produce an increasing angle when the axis of intersection is viewed looking through the fine sensor.*

4.2 Coarse Position Feedback

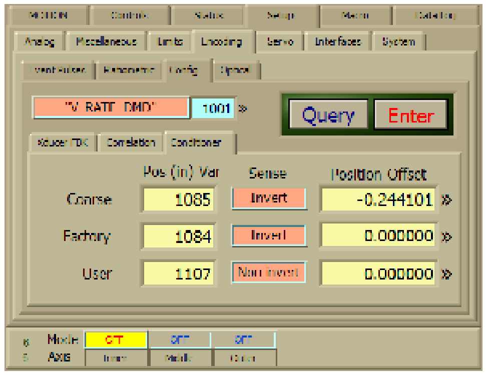
Although it is not absolutely necessary to have a coarse sensor (dual mode encoding) it is highly recommended and Acutronic makes every effort to avoid “fine only” systems.

The raw coarse position (COARSE_ANG x085) is the basis for generating a low resolution angle that spans the Full Scale Position. This requires that a Coarse (first) Correlation block be configured to deal with the coarse sensor scaling (speed) and turns counting (ref_var). A single speed (2 pole) resolver directly coupled to the axis will have a raw scaling of ±0.5 corresponding to ±0.5 revolutions. If a resolver with more than two poles is used,



then the absolute coarse range will be restricted, and the correlation **speed** is selected appropriately. The correlation panel shown here configures a single speed resolver and sets the output of the Coarse Conditioner (COARSE_COND **x207**) as the measurement variable. If the coarse Look-up Table is used, then the measurement variable is (LUT_COARSE_OUT **x240**) instead. The reference variable is specified as the normalized position estimate (POS_EST_NORM x168) and is used to allow accumulation of turns for systems that are scaled for multiple revolutions. If the coarse reference variable is set to the Zero variable (x118) then the coarse reference will be scaled by the speed and output without additional turns information (range of one revolution). Optionally, a third sensor can be input to the system, scaled in revolutions and used as the reference variable to count turns in an absolute manner.

The Coarse Conditioner modifies COARSE_ANG x085 by first adding a coarse *Position Offset* and then inverting the sign as required by the *Sense* control. The coarse conditioned output variable (COARSE_FBK **x163**) is scaled in revolutions (absolute base range) and may have a range that extends over multiple revolutions.



Verify Coarse Feedback: Select variable Coarse_ANG **x085** in a readout window and verify that it is encoding coarse position. As the axis is rotated, verify that the feedback magnitude Sqrt(S^2+C^2) **x206** is fairly constant and close in value to the set point (7.5). If this is not the case, then check the demodulated feedback variables COARSE_SINE **x203** and COARSE_COS **x204** and verify that each signal is modulating ±7.5 volts as the axis is rotated through the range of a coarse cycle. Do not proceed until this condition is achieved. The set point can be reduced if the transformation ratio of the resolver is too low. The Loss of Feedback detection must be reduced accordingly.

Based on the factory-defined convention for axis rotation sense, make a note of the direction of the coarse angle for future reference:

COARSE Direction CW____ or CCW____.

Verify that the fine rotation sense defined in the previous section is the same direction as the coarse sensor. If they are the same then proceed to the next section. If the coarse and fine sensors are encoding in opposite directions, then the sense of the coarse measurement must be reversed. In the Conditioner panel, note the current coarse sense, then select and enter the other sense.

4.3 Coarse Calibration Procedure

The coarse calibration involves the (second) Coarse/Fine correlation block which uses the COARSE_FBK **x163** as a reference variable, and the FINE_ANG **x108** as the measurement angle. The measurement angle is scaled by the (fine) *second_speed* and is then correlated with the reference. The position that results from the correlation is output as the composite feedback (COMP_FBK **x084**) and is scaled in the base engineering units (revolutions). The correlation error (COMP_CORR_ERR **x109**) is also generated and provides a measure of the coarse sensor error relative to the high accuracy composite position. This variable can be used to calibrate/model the coarse sensor errors in order to ensure proper correlation at all axis positions.

Step 1: In the [Setup:Encoder:Config:Conditioner] panel of the Operator Interface (OI), set the **Coarse Position Offset** to 0.0.

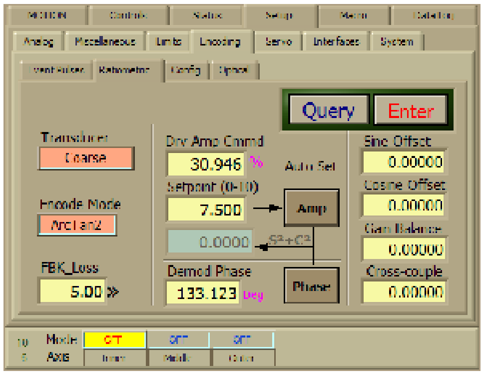
Step 2: Setup two analog outputs as follows:

Variable	Max	Min	Sensitivity
COMP_FBK x084	+0.5	-0.5	0.05 rev/V
COMP_CORR_ERR x109	+0.0028	-0.0028	0.1 deg/V

Also place these variables in readout windows for the axis being calibrated.

Step 3: Set up an X-Y scope with x084 on the x-axis and x109 on the Y-axis. Set the sensitivities on both channels to 2 V/div.

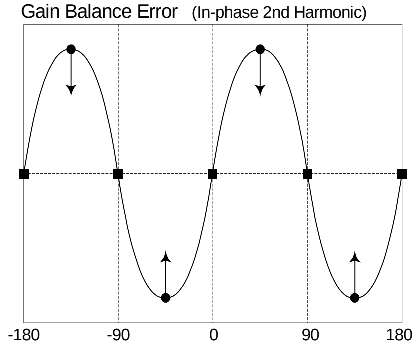
Step 4: Rotate the axis through the full range of motion and observe the coarse error behavior. First and second harmonic errors can be compensated using the *Sine/Cosine Offset, Gain Balance* and *Cross Coupling* controls in the [Setup:Encoder:Ratiometric] panel.



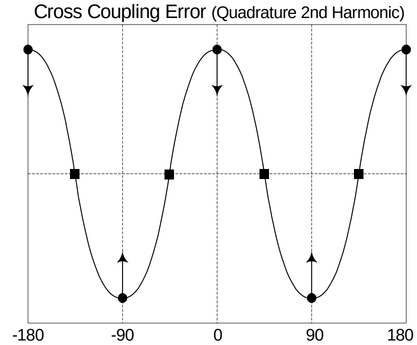
Note: *If the discontinuities in the waveform occur, this is due to mis-correlation. These are eliminated first by minimizing the systematic fundamental and second harmonic errors and/or by adjusting the* Coarse Offset *in the Coarse Conditioner to center the average error around zero.*

Step 5: If a second harmonic error is discernable, then determine if it is in-phase or in quadrature and adjust the corresponding gain in the Ratiometric panel. It is possible that both errors are present and the optimal adjustment may take several attempts to minimize the error (flatten the line). When only fundamental errors remain then proceed to Step 6.

Gain Balance Error (In-phase 2nd Harmonic)

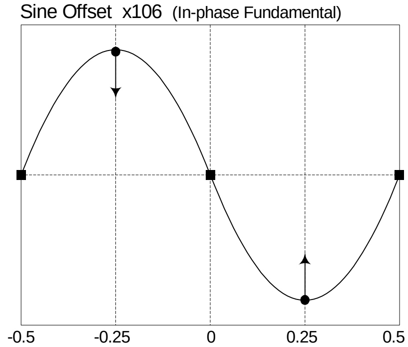


Cross Coupling Error (Quadrature 2nd Harmonic)

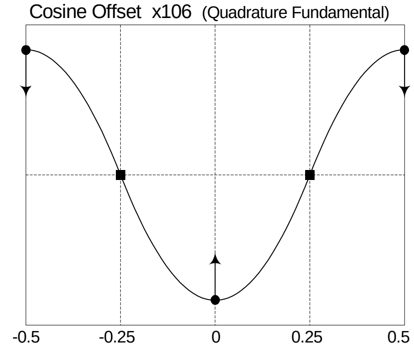


Step 6: If a fundamental harmonic error is discernable, then determine if it is in-phase or in quadrature and adjust the corresponding offset in the Ratiometric panel. It is possible that both errors are present and the optimal adjustment may again take several attempts to minimize the error.

Sine Offset x106 (In-phase Fundamental)



Cosine Offset x106 (Quadrature Fundamental)



Step 7: This step assumes that the peak-peak magnitude of the coarse error was successfully adjusted to < 0.4° (two divisions on the scope) to ensure reliable correlation. Determine the average value of the error from zero and enter the negative of this value into the *Coarse Offset* in the Coarse Conditioner panel (the sign may need to be inverted). Note, if *Coarse Offset* was not zero during the calibration, then the residual offset must be added to the current *Coarse Offset. Finally, v*erify that the coarse error is now centered around zero.

Step 8: Remember to save the default system configuration if the calibration is to be made permanent.

4.4 Fine Calibration Procedure

The fine calibration procedure follows the coarse procedure and it is assumed that the coarse/fine measurement system is functioning properly. It may be desirable to complete the fine calibration after the servo loop has been set up and the system can safely be servoed.

Adjustments made to calibrate the fine sensor will not have an impact on the previous coarse position setup/calibration nor on the servo tuning.

4.4.1 Fine Calibration Using the Phasor Magnitude

The position encoding technique used in the Acutrol3000 instrumentation is a ratiometric amplitude modulation scheme; however, the feedback signals are generally compromised by various systematic errors.

This procedure attempts to minimize the effect of DC offsets, relative gain differences of the sampling channels and cross coupling between the channels. There may be other sources of error that remain uncompensated, however for Inductosyn based systems this procedure is very effective.

The Acutrol3000 instrumentation incorporates a patented technique to identify and minimize the systematic encoding errors of the fine position sensor. The encoded position (angle) is computed as:

Θ_p = ATAN2(E1/E2)

Where, E1 and E2 are the compensated digital feedback amplitudes representing the sin and cosine of the transducer mechanical coupling angle (Θp). If errors are present in E1 or E2 then the computed angle will contain errors and the phasor magnitude will fluctuate accordingly.

The feedback signals have error terms indicated in **Bold** below:

E1 = A*sin(Θm)+**OFFsin**+A***COUPLING***cos(Θm)

E2 = A(1+**GAIN**)*cos(Θm)+**OFFcos**+A***COUPLING***sin(Θm)

and the phasor amplitude P = SQRT($E1^2$+ $E2^2$).

After simplification, the error sources of the phasor magnitude are summarized as a function of the fine sensor angle:

$P^2 = A^2$ + 2*A*OFFsin*sin(Θm) + 2*A*OFFcos*cos(Θm)

+A2*GAIN*cos(2Θm)/2+2*A2*COUPLING*sin(2Θm).

Note that all terms of the square of the phasor error have first order sensitivities to their corresponding measurement error sources, and that they are independent of each other.

The calibration technique used in the Acutrol3000 determines position errors without the need of an external reference. This is accomplished by exploiting the deterministic relationship between the transducer measurement errors and the modulation of the phasor amplitude of the feedback signals.

The phasor magnitude (Sqrt(Sin^2+Cos^2) **x106**) is computed in real-time and is plotted as a function of the fine angle (Fine_Ang **x108**); the harmonic shape and amplitude reveal the nature of the spatial encoding errors.

The procedures that follow define a systematic approach to properly adjust the ratiometric calibration parameters. Adjustments are made to minimize the variation of the phasor amplitude and consequently the position encoding errors.

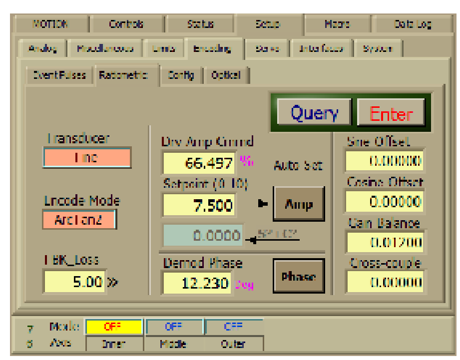
Step 1: Setup two analog outputs as follows:

Variable	Max	Min	Sensitivity
FINE_ANG x108	+0.5	-0.5	0.05 rev/V
Sqrt(Sin^2+Cos^2) x106	8	7	0.05 V/V

Also place these variables in readout windows for the axis being calibrated.

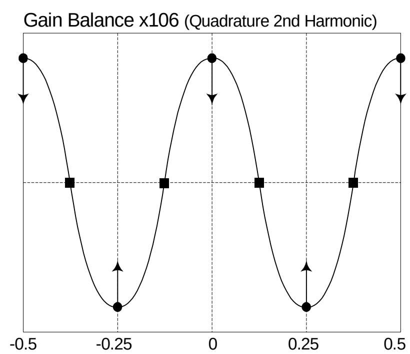
Step 2: Set up an X-Y scope with x108 on the x-axis and x106 on the Y-axis. Set the sensitivities on both channels to 2 V/div.

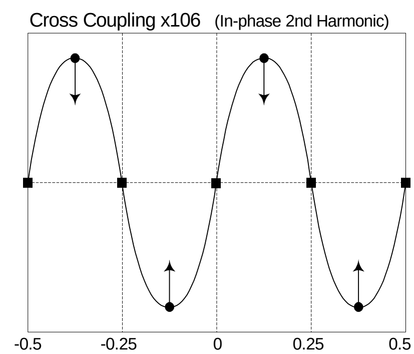
Step 3: Servo the axis if possible and rotate the axis continuously at 50°/sec. If the axis is limited rotation, then operate the system in Synthesis mode and compute an amplitude and frequency that achieve the required rate over as much of the position range as possible. By careful selection of the demand set points and the Synthesis mode limits, a distorted sine wave can usually be generated that has an extended range of constant rate. This is the ideal zone to view the plots using the oscilloscope.



First and second harmonic errors can be compensated using the *Sine/Cosine Offset, Gain Balance* and *Cross Coupling* controls in the [Setup:Encoder:Ratiometric] panel.

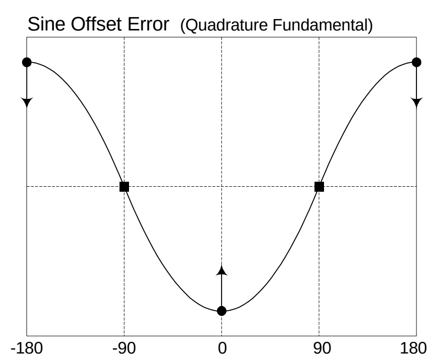
Step 4: If a second harmonic error is discernable, then determine if it is in-phase or in quadrature and adjust the corresponding gain in the fine Ratiometric panel. It is possible that both errors are present and the optimal adjustment may take several attempts to minimize the error (flatten the line). When only fundamental errors remain then proceed to Step 5.

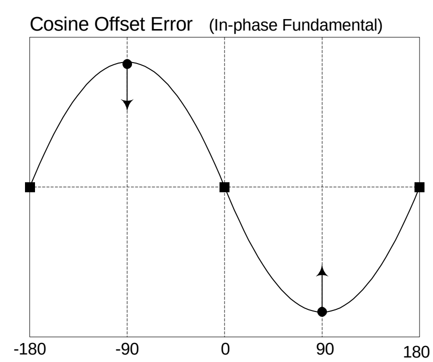




Step 5: If a fundamental harmonic error is discernable, then determine if it is in-phase or in quadrature and adjust the corresponding offset in the Ratiometric panel. It is possible that both errors are present and the optimal adjustment may again take several attempts to minimize the error.

When the variation of the phasor magnitude Sqrt(Sin^2+Cos^2) is minimized then this procedure is complete.





4.4.2 Fine Calibration Using the Observer Position Error

In general, position measurements are made statically using an external reference is such as an ultradex™ or a multi-faceted mirror. This procedure defines a means to measure position errors dynamically using the estimated position output from the Observer as a reference. The (Position Estimate x082) is naturally smoothed by the inertia of the axis and further filtered due to the finite tracking bandwidth of the Observer. The systematic errors, which are present on the position feedback can be identified and compensated as long as they are stable. The fundamental and second harmonic errors can be eliminated using the ratiometric calibration constants, other systematic errors must be compensated using the look-up table error modeling.

This method of measuring the position error can be very effective in systems with continuous rotation because the axis must be rotated at a rate that produces systematic position sensor errors at frequencies greater than the bandwidth of the observer. In an effort to enhance the sensitivity and accuracy of this method, the bandwidth of the Observer can (temporarily) be reduced.

Note: *This method can also be used to identify other systematic errors such as cogging torque. The frequency of an error identifies its source; care should be taken to ensure that the correct compensation parameters are used to correct a specific systematic error.*

The Observer position error is the signal that is used to dynamically extract the position error from the position feedback. This signal is generally available as the output of summer #20 (SUM20_OUT **x319**) but could be a different summer depending on the Observer topology. In most systems this variable is scaled in the user defined units of degrees.

Step 1: For the following procedures, setup two analog outputs as follows:

Variable	Max	Min	Sensitivity
FINE_ANG x108	+0.5	-0.5	0.05 deg/V
SUM20_OUT x319	+0.0028	-0.0028	0.1 deg/V

Step 2: For axes with continuous rotation, operate the axis in Rate mode and choose a rate that produces a fundamental fine cycle at least twice the Observer bandwidth. If the axis is limited rotation, then operate the system in Synthesis mode and compute an amplitude and frequency that achieve the required rate over as much of the position range as possible. By careful selection of the demand set points and the Synthesis mode limits, a distorted sine wave can usually be generated that has an extended range of constant rate. This is the ideal zone to view the plots using the oscilloscope method.

Oscilloscope Method: This dynamic calibration can be performed in a manner similar to the coarse calibration of section 0. Plot the variables defined below on an oscilloscope and minimize the position error by adjusting the fine channel gains and offsets. For the example plots to make sense (correct phase relationship) the *Factory* and *User Offsets* may need to be temporarily zeroed.

Spectrum Analyzer Method: Another approach to dynamic calibration uses a spectrum analyzer to focus on specific frequencies. By adjusting the fine channel gains and offsets, related points in the instantaneous spectra can be minimized. This process is applied to all frequencies periodic to the fine structural error. The residual error can be estimated as the root-sum-square of all of the related harmonic terms, or the power spectrum can be integrated over a frequency range and scaled by the frequency spread to produce an estimate of the position standard deviation; the square root of this value is the variance and approximated the RMS position deviation.

4.5 Summary of default Conditioner configurations

The Acutrol3000 position encoding system has three conditioner blocks that transform position data into a form required for subsequent processing. The input variable specified by **Pos(in)Var** can be any system variable permitting flexibility in the encoder architecture. Each conditioner provides scaling, offset, sense, and modulo operations on a conditioned position variable. The three conditioners perform the following functions:

- Coarse Conditioner – Prepares the raw coarse feedback position for correlation with the raw fine feedback. his conditioner is responsible for making the sense if the coarse measurement the same as the fine. The coarse offset is used to make small (usually less than one half of a fine cycle) position adjustments to align the coarse/fine overlap for correlation. This conditioner is not used to make gross coarse position offsets. The modulo is used to keep the output position in the range of ±0.5 revolutions.

- Factory conditioner – This conditioner is generally connected to the output of the second Correlation block. The input position is first scaled by the user defined scaling of the axis (**pos_FS** usually 360°/rev) then the *factory_pos_offset* is applied to set the zero position and the *factory_sense* sets the direction per the Acutronic standard convention. The modulo ensures that the factory position is constrained to the user defined position range. The position output from this conditioner is scaled in user engineering units and establishes the basis for other scaled position variables.

- The User Conditioner is unity scaled and provides a facility to redefine the axis zero position and the sense of the direction of rotation. The modulo is again required to ensures that the user position is constrained to the user defined position range.

This table summarizes the Conditioner blocks for a standard dual-transducer position encoding scheme.

Conditioner	Output Variable Name	Variable Number	Gain	Modulo Range	Modulo Offset
Coarse	COARSE_COND	x207	1	1	0
Factory	FACT_POS_FBK	x107	Pos_SF	FS_pos	mod_off
User	POSN_FBK	x166	1	1	mod_off

4.6 Miscellaneous Configuration Notes

- The user conditioned position variable should not be specified as the reference range for look-up tables or 3-phase motor commutation blocks because these process require an absolute/stable reference once calibrated. Instead use the raw FINE_ANG x108, the raw COARSE_ANG x085, the COMP_FBK x084, or the FACT_POS_FBK x107.

- Care must be taken whenever the encoder block connections are redefined. Each block is executed in a specific order and connections could be defined that allow the use of data that is old by one frame.

- Be careful to specify all variables consistently with their axis number. Specifying variables from another axis is not illegal but will certainly cause undesirable results if done unintentionally.

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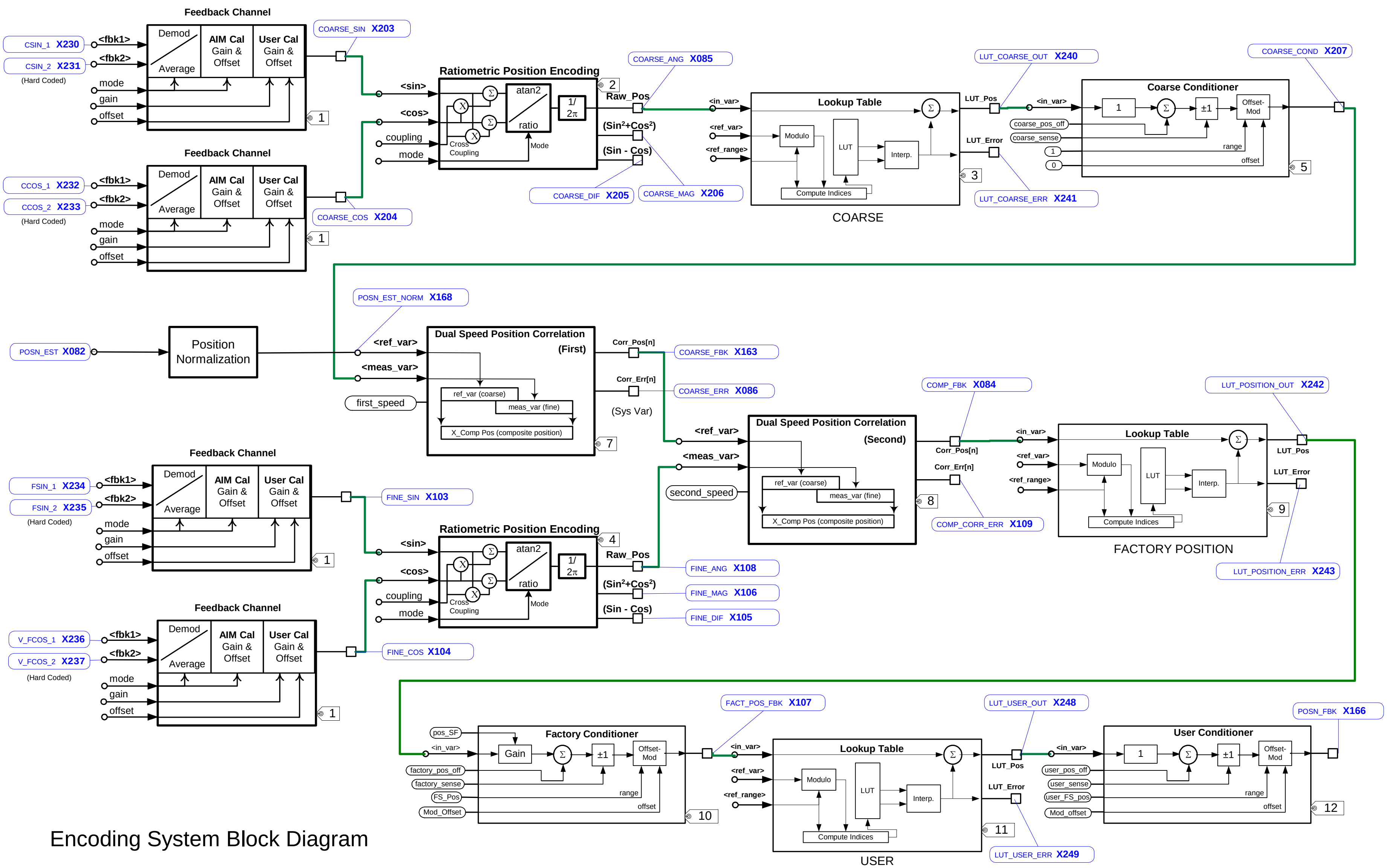

Encoding System Block Diagram