INSTALLATION AND OPERATING INSTRUCTIONS
FOR FARRAND 220500 ABSOLUTE WITH INCREMENTAL
CONVERSION SYSTEM BOARD

Engineering Report 89801

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Table of Contents

1. Overview .................................................................................................................................................................3
2. Installation ............................................................................................................................................................... 3
   2.1. Static Sensitivity ............................................................................................................................................... 3
   2.2. Associated Documentation ................................................................................................................................ 3
   2.3. Mechanical Installation of AWICS Board ........................................................................................................... 3
      2.3.1. Card Cage Mounting ........................................................................................................................................ 3
      2.3.2. Non-Card Cage Mounting ........................................................................................................................... 3
   2.4. Electrical Setup ................................................................................................................................................ 4
      2.4.1. Wiring Information .......................................................................................................................................... 4
      2.4.2. Optional Readout Software .......................................................................................................................... 4
      2.4.3. Connector Sources ......................................................................................................................................... 4
      2.4.4. Load Resistance ............................................................................................................................................ 4
      2.4.5. Power Supply Reversal .................................................................................................................................. 4
   2.5. Options in Installation ..................................................................................................................................... 4
      2.5.1. Positive Direction Sense ............................................................................................................................... 4
      2.5.2. Output Data Multiplexing .......................................................................................................................... 5
   2.6. Preamplifier Options ....................................................................................................................................... 5
   2.7. Cable Lengths ................................................................................................................................................... 5
3. Excitation Level and Phase Adjustment .................................................................................................................... 5
   3.1. Excitation Power Limits .................................................................................................................................... 6
   3.2. Excitation Level Adjustment ............................................................................................................................. 6
      3.2.1. Direct output .................................................................................................................................................. 6
      3.2.2. Series resistor ............................................................................................................................................... 6
      3.2.3. Matching transformer .................................................................................................................................... 6
      3.2.4. Excitation Level Adjustment Procedure .................................................................................................. 6
   3.3. Phase Adjustment ............................................................................................................................................ 7
      3.3.1. Fine Converter Phase Adjustment Procedure: ............................................................................................ 7
      3.3.2. Coarse Converter Phase Adjustment Procedure: ......................................................................................... 7
4. Sine/Cosine Balance Adjustment ............................................................................................................................. 7
   4.1. Gain Balance Method 1: Field Balance by Accuracy Measurement ................................................................. 7
      Figure 1. Balance Error ........................................................................................................................................... 8
   4.2. Gain Balance Method 2: Field Balance Without Accuracy Measurements ....................................................... 9
      Figure 2. Connection for Locating a Precise 1/8th Cycle Point ......................................................................... 9
   4.3. Gain Balance Method 3: Indirect Balance .......................................................................................................... 10
      4.3.1. Preamplifier Balance ................................................................................................................................. 10
      Figure 3. Setup for Preamplifier Balance and Source Resistance Balance Procedures ..................................... 10
      4.3.2. Slider or Stator Balance ............................................................................................................................ 10
      4.3.3. 220500 Input Amplifier Balance ............................................................................................................. 11
      Figure 4. Setup for 220500 Board Input Amplifier Balance Procedure ............................................................ 11
5. Alignment of Correlation Circuit ............................................................................................................................ 11
   5.1. Zero Offset Alignment ....................................................................................................................................... 11
      Figure 5. Oscilloscope Display of TP7 Waveform: Offset Correction Required ............................................... 12
      Figure 6. Oscilloscope Display of TP7 Waveform: Proper Operation ................................................................. 12
      Figure 7. Oscilloscope Display of TP7 Waveform: Excessive Errors .................................................................. 13
   5.2. Check of Direction Sense .................................................................................................................................. 13
      Figure 8. Oscilloscope Display of TP7 Waveform: Positive Motion ................................................................. 13
      Figure 9. Oscilloscope Display of TP7 Waveform: Negative Motion ................................................................. 14
6. Theory of Correlation Circuit Alignment .............................................................................................................. 14
      Figure 10. Oscilloscope Display of TP7 Waveform Showing Average Error ......................................................... 15
7. Cyclic Accuracy Analysis ......................................................................................................................................... 16
   7.1. Cross Coupling between Excitation and Sine or Cosine .................................................................................. 16
      Figure 11. Cross Coupling: Excitation to Sine or Cosine .................................................................................... 16
   7.2. Sine/Cosine Balance Error ................................................................................................................................. 16
      Figure 12. Balance Error ......................................................................................................................................... 17
   7.3. Cross Coupling Between Sine and Cosine Wiring .............................................................................................. 17
      Figure 13. Cross Coupling: Sine to Cosine ............................................................................................................ 17
   7.4. Fourth Harmonic Errors .................................................................................................................................. 17

Page 2 of 17
1. Overview

The Farrand 220500 Absolute with Incremental Conversion System Board (AWICS) is an electronic assembly containing two converters and the correlation logic needed to develop an absolute position output from a Farrand dual speed INDUCTOSYN® transducer, or an INDUCTOSYN® and resolver combination. The 220500 board is capable of 24 bits of absolute position data, with 16 bits allocated for fractional cycle data, and up to 8 bits available for whole cycle data. For the full specifications on the 220500 board, see Farrand Engineering Report 49801.

2. Installation

2.1. Static Sensitivity

The integrated circuits on the board are static sensitive. Whenever the board is not plugged into its socket it should be protected by a static dissipating bag such as the one it was shipped in, and should be handled at a static protected workstation. Boards returned to the factory must be repackaged using anti-static material or any applicable warrantee will be voided.

2.2. Associated Documentation

In addition to this document Farrand Engineering Report 49801 is needed for the installation of the 220500 AWICS board. ER49801 includes the following drawings:

- Drawing 220500-I Info Drawing Absolute with Incremental Conversion
- Drawing 220504 Typical Hook-up Drawing for 220500 AWICS Board
- Drawing 220520-I Information Drawing AWICS Interface Board
- Drawing 220522 Hook-Up Drawing Two Channel Preamp 218991
- Drawing 218891-I Info Drawing Two Channel Preamp 218991
- Drawing 219200-I Info Drawing Dual Channel Preamp
- Drawing 219594-I Info Drawing Two Channel Preamp Board Assy.
- Drawing A218000 Wiring Techniques and Materials

The following Farrand Engineering Reports may be needed for the installation of the Inductosyn and the 220500 AWICS board.

- Engineering Report 47401 Rotary INDUCTOSYN® Position Transducer Installation and Alignment Procedure
- Engineering Report 387A INDUCTOSYN® Accuracy

2.3. Mechanical Installation of AWICS Board

2.3.1. Card Cage Mounting

The 220500 AWICS board is designed to mount in a 3Ux220mm Eurocard subrack card cage. It has a standard 64 position DIN41612 A/C connector on one end which can be plugged into a custom backplane, a Farrand 220520 AWICS Interface Board, or a mating ribbon cable connector. Two mounting holes are provided for attaching a standard 3U front panel.

The Farrand 220520 AWICS Interface Board can be mounted on the back of a 3U subrack and used to mate to the 220500 board, see 220520-I for further info on the AWICS Interface Board. When a 220520 Interface board is used a standard interface cable is provided to connect the A quad B, and marker output signals to the Interface Board, where they are accessible on the 50 pin connector.

2.3.2. Non-Card Cage Mounting

The 220500 can be mounted, external to a subrack, using a 220520 AWICS Interface board. Four mounting holes are provided on the 220520 Interface board, and two on the 220500 board. The two
boards are mated together, via the P1-J1 connectors, and then mounted using stand-offs. When the 220500 board is mounted external to a card cage, without a Farrand 220520 Interface board, it is plugged into a mounted P1 mating connector and secured using the two mounting holes provided on the 220500.

2.4.  Electrical Setup

2.4.1.  Wiring Information

The following supporting documentation is included with Engineering Report 49801:

- Drawing 218000 Wiring Techniques and Materials. To ensure full accuracy and correct correlation, the wiring must meet these requirements and the appropriate hookup drawing should be followed.
- Drawing 220504 Typical Hook-up Drawing for 220500 AWICS Board
- Drawing 220522 Hook-up Drawing AWICS Interface Board

2.4.2.  Optional Readout Software

Software is available from Farrand which allows the output data from the 220500 board to be displayed on a PC, using an off-the-shelf digital I/O board and a Farrand 220520 interface board. The software can be used to display the absolute position, A quad B, marker, cycle zero, and correlation error. Please contact Farrand for more information on the Readout software.

2.4.3.  Connector Sources

The following list is a guide to help find the mating connectors to the I/O connections on the 220500 AWICS board.

<table>
<thead>
<tr>
<th>220500 Connector</th>
<th>Mating Connector Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>64 position female DIN41612 A/C, straight</td>
<td>Amp 650408-5</td>
</tr>
<tr>
<td></td>
<td>64 position female DIN41612 A/C, rt. angle</td>
<td>Amp 650870-4</td>
</tr>
<tr>
<td>J2</td>
<td>9 position male D-type, solder cup</td>
<td>Positronic MD9M2000X</td>
</tr>
<tr>
<td>J3</td>
<td>9 position male D-type, solder cup</td>
<td>Positronic MD9M2000X</td>
</tr>
<tr>
<td>J4</td>
<td>9 position female D-type, solder cup</td>
<td>Positronic MD9F2000X</td>
</tr>
<tr>
<td>J5</td>
<td>14 position female IDC (header)</td>
<td>Amp 746285-2</td>
</tr>
</tbody>
</table>

2.4.4.  Load Resistance

To prevent damage to the 220500 board the resistance driven by the excitation signal when no transformer is used must be at least 15 ohms. If the scale or rotor resistance is less than this value, a two-watt resistor should be connected in series with the excitation signal to increase the load resistance. This is not necessary when using an external matching transformer or when using most rotary transducers with an integral rotary transformer. The drive capability of the excitation amplifier is also dependent on ambient temperature and airflow over the power amplifiers heat sink. See section 3.1b for maximum operating temperature.

2.4.5.  Power Supply Reversal

Mis-wiring of the power supplies to the board will almost certainly result in damage. It is very important that the power supply voltages are checked before the AWICS Board is installed. Also, ensure that power is turned off during board installation.

2.5.  Options in Installation

2.5.1.  Positive Direction Sense

When used with a one-speed and an N-speed transducer, the positive direction of motion is the same for both converters, and both are connected normally. When used with an N, N-l transducer the N-l data must show positive motion in the opposite direction from the N data. To do this, the SIN HI and SIN LO connections between the Inductosyn® transducer and the N-l pre-amplifier are interchanged. (Positive motion is increasing binary output).

The absolute zero location and direction sense can be changed by modifying the wiring between the Inductosyn® and the preamp, as shown in the table below.
**Zero Point & Direction Sense**

<table>
<thead>
<tr>
<th>Zero Point &amp; Direction Sense</th>
<th>Changes At Preamp Input Connections</th>
</tr>
</thead>
</table>
| Same zero point with opposite direction sense. | Swap N COS HI & COS LO.  
Swap N-1 COS HI & COS LO. |
| Move zero point 180° with same direction sense. | Swap N-1 SIN HI & SIN LO.  
Swap N-1 COS HI & COS LO. |
| Move zero point 180° with opposite direction sense. | Swap N COS HI & COS LO.  
Swap N-1 SIN HI & SIN LO. |
| Move zero point 90° with same direction sense. | Swap N-1 SIN & COS.  
Swap N-1 COS HI & COS LO. |
| Move zero point 90° with opposite direction sense. | Swap N COS HI & COS LO.  
Swap N-1 SIN & COS.  
Swap N-1 SIN HI & SIN LO.  
Swap N-1 COS HI & COS LO. |
| Move zero point 270° with same direction sense. | Swap N-1 SIN & COS.  
Swap N-1 SIN HI & SIN LO. |
| Move zero point 270° with opposite direction sense. | Swap N COS HI & COS LO.  
Swap N-1 SIN & COS. |

**2.5.2. Output Data Multiplexing**

The output data can be accessed in two ways, as a 24 bit parallel data bus, or multiplexed onto an 8 bit data bus. When the multiplexed 8 bit data bus is used, the 8 data bits will be output over the 8 most significant bus bits (D16 – D23). The user’s system must drive the Byte Select 0 and Byte Select 1 control lines to access the desired output data, see ER49801 for more details.

**2.6. Preamplifier Options**

A number of different preamplifier types are available from Farrand, providing a choice of size, temperature range, and terminations. One of the following Farrand preamplifiers can be used: 218891, 219200 or 219594. Consult Farrand drawings 218891-I, 219200-I and 219594-I (included with ER49801) for details on these preamplifiers. Each preamplifier is supplied in several gain settings; consult the factory for the proper model. For best results, power for the preamplifiers should be taken from the connections provided for that purpose on the 220500 board Fine and Coarse preamp connectors (J2 and J3).

**2.7. Cable Lengths**

Farrand drawing A218000 supplies information on recommended cables and wiring techniques. Provided that these recommendations are complied with, the following cable lengths are possible:

(i) Transducer to preamplifier: The preamplifier should be mounted as close as possible to the transducer. The recommended maximum distance is 6ft but greater lengths are possible depending on the noise environment and wiring method.

(ii) Preamplifier to 220500 board: 400ft

- For the excitation signal, maximum cable length is usually determined by voltage drop in the cable. A 400 ft. run of 24 AWG cable, for instance, has a nominal resistance of 20 ohms compared with the resistance of an Inductosyn® scale that may be as low as 1 or 2 ohms. Excitation current and, therefore, voltage drop can be reduced by using a higher gain preamplifier or, in some cases, by locating a matching transformer close to the transducer.

- For the sine/cosine signals, attenuation in the cable is low because of the high input impedance of the 220500 board and external noise pickup, either EMI or ground induced, is the controlling factor.

(iii) Opto-Isolated RS422-A output connections (A, B, and MARKER): Cable lengths of at least 100 ft. are practical using a 24 AWG twisted pair terminated with 100 ohms. For a detailed analysis please refer to National Semiconductor's application note AN214, August 1993 *Transmission Line Drivers for TIA/EIA Standards RS422 and RS423*.

**3. Excitation Level and Phase Adjustment**

Correct operation requires the following conditions:

- Balanced (equal) sine and cosine peak input voltages of 2.0 volts rms (5.7 peak to peak) ±10%, which are set by adjusting the excitation voltage to the transducer.
- Correct phasing of the reference signal to the converter.
For the 220500 AWICS Board the signal amplitude is adjusted for both channels using the same potentiometer, while the phasing is adjusted independently for the Fine and Coarse inputs.

3.1. Excitation Power Limits
When using the 220500 AWICS Boards it is important to make sure that:

a. The output is matched correctly to the load using, if necessary, an external matching transformer or a series resistor.
b. The load impedance is not less than 15 ohms and the excitation current is not greater than 200mA.
c. The temperature on the case of the power amplifier does not exceed 85°C (185°F).
d. The maximum excitation power ratings listed in Engineering Report ER49801 are not exceeded.

Notes:
- Consult the factory for series resistor or transformer coupled configurations.
- If the excitation drive level is too high, a preamplifier with higher gain may be required.

3.2. Excitation Level Adjustment
For the Fine converter on the 220500 board it is important that the maximum sine and cosine signals should be 2.0Vrms (5.7 volts peak to peak) ±10% and undistorted. It is acceptable for the Coarse converter sine and cosine signals to be more than 10% below 2.0Vrms, since the Coarse pattern is used for correlation purposes only. The Coarse sine and cosine signals should not exceed 2Vrms +10%. If the sine or cosine waveforms displayed on the oscilloscope are distorted, or if the voltage level stated above cannot be obtained, it is probably due to a mismatch between the transducer input impedance and the excitation power amplifier on the 220500 board.

The 220500 board output voltage and the Inductosyn® input excitation voltage are computed as follows:

\[
V_e = \frac{2.0 \times V_{TR}}{G} \\
I_R = \frac{V_R}{Z_R} \\
V_O = V_R + I_R \times R_C
\]

Where:  
- \(V_R\) = excitation voltage required at input to Inductosyn®  
- \(I_R\) = excitation current  
- \(V_O\) = voltage required at output 220500 board power amp  
- \(Z_R\) = impedance of Inductosyn® excitation input at excitation frequency  
- \(R_C\) = resistance of excitation wiring  
- \(V_{TR}\) = voltage transformation ratio of Inductosyn® at actual gap  
- \(G\) = gain of preamp and 220500 board input amplifier

There are three excitation hookup possibilities (see drawing 220504):

3.2.1. Direct output
The 220500 board can be connected directly to the Inductosyn® provided that the excitation power limits of section 3.1 are satisfied.

3.2.2. Series resistor
If the impedance of the Inductosyn® is less than 15Ω either a series resistor or a matching transformer is needed to connect between the power amp and the load. The series resistor value and power rating is determined based on the voltage and current needed at the Inductosyn® input.

3.2.3. Matching transformer
In order to match the Inductosyn® rotor impedance to the power amplifier a step down transformer is connected between the excitation output and the rotor. This method allows for the most efficient power transfer between the power amp output and the Inductosyn®.

In difficult installations it may be necessary to try all three to determine which hookup meets the voltage requirement without distortion.

3.2.4. Excitation Level Adjustment Procedure
a. Adjust the “DRIVE” potentiometer on the AWICS Board so that the maximum input on the Fine
Cosine test point TP3, as the transducer moves, is an undistorted 2.0Vrms ± 10%.

Note: Counterclockwise rotation of the potentiometer increases the drive level.

Check that the excitation power level specified in section 3.1 is not exceeded.
Verify that the voltage level on the Coarse Cosine test point TP1 is between 1.5Vrms and 2.2Vrms. If the voltage is not in this range then the gain of the Coarse preamp or the gain of the Coarse input stage on the 220500 board may need to be changed.
If both the Fine and Coarse signals are within the recommended ranges, and the excitation power level is not exceeded then the excitation drive level is properly set.

3.3. Phase Adjustment
The phase of the reference signal to each converter must be adjusted to match the phase shift of the particular transducer. Inductosyn® transducers have input to output phase shifts in the range of 0° to 90° leading.
Since the phase of the sine and cosine signals switches by 180° at some points of the cycle, the system is in phase when the signal at the phase test points, TP8 and TP9, is either in phase or 180° out of phase with the sine and cosine signals.

3.3.1. Fine Converter Phase Adjustment Procedure:
a. Using a dual channel oscilloscope, connect one input to the Fine COSINE test point TP3 on the AWICS Board.
b. Connect the other input to the Fine converter reference phase test point TP9.
c. Display both oscilloscope inputs together using the "chopped" mode.
d. Position the transducer so that the COSINE signal is near its maximum amplitude.
e. Synchronize the oscilloscope to the COSINE signal.
f. Adjust the PHASE2 potentiometer until the two signals are either in phase or 180º out of phase.
g. The Fine converter is now properly phased.

3.3.2. Coarse Converter Phase Adjustment Procedure:
a. Using a dual channel oscilloscope, connect one input to the Coarse COSINE test point TP1 on the AWICS Board.
b. Connect the other input to the Coarse converter reference phase test point TP8.
c. Display both oscilloscope inputs together using the "chopped" mode.
d. Position the transducer so that the COSINE signal is near its maximum amplitude.
e. Synchronize the oscilloscope to the COSINE signal.
f. Adjust the PHASE1 potentiometer until the two signals are either in phase or 180º out of phase.
g. The Coarse converter is now properly phased.

4. Sine/Cosine Balance Adjustment
To achieve the expected system accuracy, the total gain of the sine channel must be closely matched to the gain of the cosine channel for both the Fine and the Coarse transducers. All gain balance methods discussed below are used for both the Coarse and the Fine Inductosyn® outputs. The gain balance adjustments on the preamplifier and 220500 input amplifier compensate for differences in the resistance of the transducer’s sine and cosine patterns and cabling, as well as for the characteristics of the particular preamplifier. Any difference in gain directly affects the position error within the transducer cycle. The type of error produced from a gain balance error is shown in figure 1. The following methods can be used to set the input amplifier and preamplifier gain balance:

• Field balance by accuracy measurement - recommended if suitable accuracy measurement is available, described in section 4.1 below.
• Field balance without accuracy measurement - the system is positioned to a precise 45° point by temporarily rewiring the hookup to the sine and cosine windings and moving to a position where the output is a null. The input amplifier’s, or the preamplifier’s, balance potentiometer is then adjusted for the correct reading. This method is described in section 4.2 below.
• Indirect balance method - The preamplifier is balanced by itself and the slider, or stator, sine and cosine resistances are balanced using a Wheatstone bridge with series resistance added as necessary to balance the bridge. This method is described in section 4.3 below.

4.1. Gain Balance Method 1: Field Balance by Accuracy Measurement
Providing that the required measurement equipment is available this is the preferred method to balance the
sine and cosine channels. In this method the actual error of the total system including the transducer, preamplifier, AWICS Board and wiring is measured over one transducer cycle by comparison with an accuracy standard. For a linear system this standard can be a laser interferometer, step gage, or gage blocks; for a rotary system it can be a tangent arm or autocollimator with angle gage blocks. The balance potentiometer on the AWICS board input amplifier (or on the preamplifier) is adjusted, if necessary, to give the minimum error. After the adjustments are complete the accuracy measurements are repeated to verify that the balance is set properly.

a. Set up the accuracy measuring equipment.
b. Make an initial balance adjustment using a digital voltmeter. Measure the peak voltage of the cosine output and adjust the input amplifier potentiometer (R40 for the Coarse converter, R41 for the Fine converter) to bring the sine output to the same peak value. Note: Preamplifiers are usually balanced before shipment, so typically only the gain balance pots on the AWICS board would be adjusted.
c. Position the Inductosyn® transducer so that the CYCLE ZERO output from the AWICS board goes HIGH, or where all of the fractional output bits are zeroes. (To perform this procedure for the Coarse converter either install a jumper between J10 pin 1 and pin 2, or install a jumper between J10 pin 2 to pin 3 and provide a LOW level to P1-11C.) CYCLE ZERO occurs at one of the two points in the transducer cycle where the signal at the SINE test point (TP2 for the Coarse converter, TP4 for the Fine converter) is zero. This is the starting point for the following error measurements.
d. Starting at this point, make eight moves, each equal to 1/8 of a transducer cycle, as measured by either the converter or the accuracy measuring equipment.

<table>
<thead>
<tr>
<th>Transducer Cycle</th>
<th>Spacing for Readings</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 in</td>
<td>0.0250 in</td>
</tr>
<tr>
<td>0.1 in</td>
<td>0.0125 in</td>
</tr>
<tr>
<td>2. mm</td>
<td>0.0098425 in (0.25 mm)</td>
</tr>
<tr>
<td>720 pole</td>
<td>0.125 degree (7° 30.0&quot;)</td>
</tr>
<tr>
<td>512 pole</td>
<td>0.1758 degree (10° 32.8&quot;)</td>
</tr>
<tr>
<td>360 pole</td>
<td>0.25 degree (15° 00.0&quot;)</td>
</tr>
<tr>
<td>256 pole</td>
<td>0.3516 degree (21° 5.6&quot;)</td>
</tr>
</tbody>
</table>

At each of these points, record the distance from the starting point both as measured by the 220500 board and by the accuracy standard. The position as indicated by the converter minus the position measured by the accuracy standard is the error. Plot this error as a function of position on graph paper.

A curve like Figure 1 with two positive peaks and two negative peaks located at 1/8, 3/8, 5/8, and 7/8 of the cycle shows a gain balance error. The curve might be inverted from that shown.
e. Return the Inductosyn® transducer to the first peak. Remove the RTV silicone rubber from the balance potentiometer (R40 for the Coarse converter, R41 for the Fine converter) on the 220500 board and adjust the potentiometer to reduce the position error to zero.

f. Repeat the procedure starting at (c). Note that when the first and third peaks go more negative the second and fourth peaks go more positive. If the curve is not exactly as shown in figure 1, a compromise adjustment should be made to minimize the overall error. When the error measured in Step (d) is within acceptable limits, the gain balance procedure is complete for this converter (Fine or Coarse).

g. Secure the shaft of the potentiometer on the 220500 board with RTV.

h. If the error curve has a different shape, refer to section 7 or Engineering Report ER387A.

4.2. Gain Balance Method 2: Field Balance Without Accuracy Measurements

In this method, the position of an exact 1/8 cycle point is determined by temporarily connecting the sine and cosine windings in series, as shown in Figure 2, and moving the transducer to null their combined outputs. The transducer position is locked and the normal wiring is restored. The balance potentiometer on the preamplifier is then adjusted, if necessary, until the position output from the 220500 board is at an exact 1/8th cycle point.

a. Make an initial balance adjustment using a digital voltmeter. Measure the peak voltage of the Cosine (TP1 for Coarse, TP3 for Fine) output and adjust the potentiometer (R40 for the Coarse converter, R41 for the Fine converter) to bring the Sine voltage to the same peak value. Note: Preamplifiers are usually balanced before shipment, so typically only the gain balance pots on the 220500 board would be adjusted.

b. Synchronize an oscilloscope (on external sync) to the excitation input to the transducer or to the signal at the Phase Test Point (TP8 for Coarse, TP9 for Fine) on the 220500 Board. Display the Sine signal test point (TP2 for Coarse, TP4 for Fine). Position the transducer so that a signal level of at least 1volt peak to peak is displayed. Adjust the horizontal position so that either the positive or negative peak of the displayed signal is at the exact center of the display. Do not change these settings until the balance adjustment is finished.

c. Disconnect the wires connected to the slider or stator from the preamplifier (Fine or Coarse) SIN LO and COS HI and LO terminals (“B”, “C”, and “D-J”). Connect the two transducer windings in series to the SINE input terminals as shown in Figure 2.

d. With the 22500 board providing excitation to the scale or rotor, position the Inductosyn® transducer manually to produce a minimum signal on the oscilloscope. If this signal is not zero, the minimum occurs when the displayed signal crosses the zero axis of the oscilloscope display at the exact center of the display (as located in (b) above). At this point the remaining signal out of the preamplifier is 90° out of phase with the normal preamplifier output. The minimum signal at the center of the display should be within 0.5mV of 0 volts.
e. Clamp the slider or rotor in this position.

f. Check to make sure that the null condition achieved in step (d) above has not been disturbed.

g. Reconnect the wires from the slider or stator to the preamplifier assembly in the normal way as shown in drawing 220504.

h. The 220500 board should now be close to a 1/8th cycle point. This can be observed by looking at the fractional data output from the board; it should be close to displaying a 1/8th point value (0x2000, 0x6000, 0xA000, or 0xE000 for a 16 bit system).

i. Remove any RTV from the potentiometer on the 220500 board (R40 for the Coarse converter, R41 for the Fine converter) and adjust the potentiometer until the fractional part of the output reads a true 1/8th point value. At this point the SIN (TP2 for Coarse, TP4 for Fine) and COS (TP1 for Coarse, TP3 for Fine) signals should be equal.

j. When the adjustment is complete, secure the potentiometer on the 220500 board with RTV.

k. Remove the clamp from the rotor or slider.

4.3. **Gain Balance Method 3: Indirect Balance**

The indirect balance method consists of balancing the slider or stator, the preamplifier, and the 220500 board separately and does not involve positioning the transducer elements in any particular relationship to each other.

4.3.1. **Preamplifier Balance**

The preamplifier is connected as shown in Figure 3. The oscillator amplitude is adjusted for a preamplifier output of approximately 5V peak to peak. The potentiometer on the preamplifier is then adjusted for a minimum output into the oscilloscope terminals.

Note: The transformer must provide excellent electrostatic shielding between input and output, the correct end of the output winding should be grounded and the input and output leads should be separated. Suitability of the setup can be checked by connecting both ends of the input winding to the same preamplifier output. The output signal, divided by the turns ratio of the transformer, should be less than 0.05% of the preamplifier output. After the adjustment is completed, the test circuit should be removed.

![Figure 3. Setup for Preamplifier Balance and Source Resistance Balance Procedures.](image-url)

4.3.2. **Slider or Stator Balance**

The resistive balance of the sine and cosine windings of the slider or stator together with cable resistance is checked using a DC Wheatstone bridge. Imbalance between the two source resistances...
should be less than 0.05%. Provision has been made for mounting balancing resistors on preamplifier 218891. If preamplifier 219200 or 219594 is used, balance resistors must be supplied and mounted by the user. Resistors used for balance should be wire wound, metal film, or equivalent temperature stable type.

### 4.3.3. 220500 Input Amplifier Balance

The 220500 board is connected as shown in Figure 4. This setup uses the signal coming back from the Inductosyn®, via the preamp, as the test input source. The Sine and Cosine inputs (done for the Fine and then for the Coarse) to the 220500 board are driven from the same signal. The Inductosyn® is adjusted for the maximum preamp output on the channel that is being used. The potentiometer on the 220500 board input amplifier is then adjusted for a minimum output into the oscilloscope terminals.

Note: The transformer used must provide excellent electrostatic shielding between input and output, the correct end of the output winding should be grounded and the input and output leads should be separated. Suitability of the setup can be checked by connecting both ends of the input winding to the same preamplifier output. The output signal, divided by the turns ratio of the transformer, should be less than 0.05% of the preamplifier output. After the adjustment is completed, the test circuit should be removed.

![Figure 4. Setup for 220500 Board Input Amplifier Balance Procedure.](image)

### 5. Alignment of Correlation Circuit

#### 5.1. Zero Offset Alignment

The correlation card must be aligned to compensate for any offset between the coarse and fine data. This alignment requires the use of an oscilloscope connected to the test point on the correlation card. The oscilloscope display is set for DC and adjusted so that zero volts is near the bottom of the display and 1.5 volts is at the center of the display. The display will be a DC level while the transducer is not moving. As the measured axis is moved the DC level will change. Set the horizontal sweep of the oscilloscope slow enough so that a reasonably large number of levels will be displayed on one sweep while the axis is moving. Figures 4, 5, and 6 are idealized pictures of possible oscilloscope displays. (Only one sweep is shown.)
Figure 5. Oscilloscope Display of TP7 Waveform: Offset Correction Required

Figure 5 shows normal operation except that the signal is displaced toward the top of the display. After the level reaches the top of the display, it moves off the top and reappears on the bottom. This "wrap around" corresponds to the output data taking an improper jump in value. This must be corrected. The four Pattern Offset Switches (numbered 0, 1, 2 and 3 on the circuit board) are provided for this purpose.

Figure 6. Oscilloscope Display of TP7 Waveform: Proper Operation

Changing the pattern offset switch setting will move the whole display up or down. Switch 3 moves it 8 levels, switch 2 moves it 4 levels, switch 1 moves it 2 levels and switch 0 moves it by 1 level. The pattern offset switch zero setting is with all of the DIP switches up (when looking at the board with the 64 position connector on the right). For the system shown in Figure 5, if the level is moved down by 6 levels (or up by 10), the waveform shown in Figure 6 results. Figure 6 shows the signal centered within its range and not going near either limit. If it stays within this range for the complete travel of the axis, correlation will be successful.

Figure 6 shows the condition that results from excessive gain balance or cross coupling errors. The difference signal exceeds the limits on both the high and the low end; the zero offset switches cannot correct for this condition. Consult section 7, Engineering Report 387A INDUCTOSYN® Accuracy, and drawing A218000 Wiring Techniques and Materials for more information, both engineering reports are available from Farrand. It will be necessary to use some or all of the techniques described to reduce the errors.
5.2. **Check of Direction Sense.**

Test point TP7 can also be used to check the direction sense. If the Sine and Cosine inputs to the Coarse converter are removed (disconnect cable connected to J2) test point TP7 shows only the effect of the fine converter data. Figures 8 and 9 show the resulting patterns. Figure 8 shows the downward sloping staircase produced by positive motion and Figure 9 shows the upward sloping staircase resulting from negative motion. Removing the Sine and Cosine inputs to Fine converter (disconnect cable connected to J1), and adding a jumper from J10-2 to J10-3 (or from J10-1 to J10-2 and driving the COARSE TEST control line, P1-11C, low) causes only the results of the coarse data to be displayed on TP7. A given direction of axis motion should produce the same direction sense in both converters for one-speed and N-speed systems and opposite direction senses for N, N-1 systems.

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**Figure 7. Oscilloscope Display of TP7 Waveform: Excessive Errors**

**Figure 8. Oscilloscope Display of TP7 Waveform: Positive Motion**
In most systems counter-clockwise rotation of the disk closer to the observer should produce positive rotational data, although some systems may use the opposite directional sense. With both converters connected to the correct Sine and Cosine inputs (normal operation), the pattern in Figure 6 shows proper operation. If either of the patterns shown in Figure 8 or Figure 9 occurs it indicates either very large errors or one converter connected with the wrong rotation sense.

6. Theory of Correlation Circuit Alignment

In a system with a dual-speed INDUCTOSYN® transducer, design and manufacturing limitations prevent the one-speed zero from occurring at a zero of the N pattern. In general, the one-speed zero may occur at any point in the N cycle. In addition, the difference between the position as shown by the one-speed data and the position as shown by the N-speed data will change as the axis moves, because of various small errors. When using the 220500 board the maximum error allowable between the N and N-1 patterns is dependent on the pattern pitch and the resolution of the N-1 pattern data (which is the resolution of the correlated bits). The maximum error allowable between the N and N-1 patterns can be calculated using the equation below, this includes all cyclic and external error sources.

\[
\text{Error} = \frac{360^\circ}{8} \times \frac{3600\text{sec}}{2} \times \frac{1^\circ}{R}
\]

Where:
- \(N\) = Pole count of N pattern on Inductosyn®
- \(R\) = Resolution of N-1 pattern data

For example, a 512/510 Inductosyn with 12 bit resolution on the 510 pattern has maximum allowable error of 19.78 seconds, beyond which correlation will not be possible using the 220500 board.

The Pattern Offset Switches allow a constant to be added to or subtracted from the one-speed data before the correlation so that the mean difference between the position as shown by the one-speed and N-speed data words will be nearly zero.

Test point TP7 provides a graphic image of the correlation on an oscilloscope. The voltage at this test point is an analog representation of the difference between the positions as shown by the one-speed and N-speed data words at the present position (after correction by the Pattern Offset Switches). If both data words show the same position, the voltage is 1.5 volts. The voltage is above this value when the N-speed data is ahead of the one-speed data and below it when the one-speed data is ahead of the N-speed data. This signal is derived digitally and it can have only 16 values, 7 larger than 1.5 volts and 8 smaller. This spread of signals represents the correlation range of the circuit.

In normal operation, the voltage at the test point will shift up and down a few levels either side of the center value because of small inevitable errors in the one-speed data. If the Pattern Offset Switches are not set properly, the Zero Offset error and the small errors combined may cause the total error to exceed the limits of the correlation range. The circuit cannot detect that this has happened. For example, if the true error is 5/8 of an N cycle, the circuit must treat it as an error of 3/8 of a cycle in the other direction. Therefore, when the difference passes either limit point, the error display signal "wraps around" the range and the output number jumps to a value one N cycle too high or too low.
Figure 10. Oscilloscope Display of TP7 Waveform Showing Average Error

The difference between the middle of the displayed data and the no error condition (1.5 volts DC) equals the amount of the Pattern Offset correction that must be inserted with the switches, see Figure 10. Perfect input data, i.e. a straight line on the oscilloscope display, is not to be expected. Small errors, including quantization, are inevitable. In an N, N-1 system the signal will shift up and down by one level even with no errors at all because of the way the coarse data is made by combining two numbers which are not constrained to change at the same time.
7. **Cyclic Accuracy Analysis**

The error curve, plotted in section 4.2, for sine/cosine gain balance may differ from the ideal curve shown in figure 11, below. This is because other error sources with different characteristics may be contributing to the overall result. These sources include the converter integrated circuit and the error sources discussed below. The overall error curve will, therefore, be a sum of the individual error contributions. These errors can be minimized by using the wiring techniques and materials recommended in drawing A218000.

7.1. **Cross Coupling between Excitation and Sine or Cosine**

This is a first harmonic error - it completes one cycle as the Inductosyn® travels through one cycle. The polarity of the error signal may be inverted from that shown and may be phase shifted. The phase shift occurs because, for an Inductosyn® transducer, the sine and cosine signals lead the Excitation signal by 0 to 90 degrees.

![Figure 11. Cross Coupling: Excitation to Sine or Cosine](image)

This type of cross coupling is often electromagnetically induced and can be minimized by keeping the excitation cable well separated from the sine and cosine cables and by maintaining a tight twist on all unshielded sections of wiring. The sine and cosine signals prior to amplification are very sensitive to pick up and special care is necessary if these signals are routed through the same connector as the excitation signal. In general, and especially for high accuracy systems, it is advisable to use a separate connector for the excitation signal – for more information see drawing A218000.

Another possible cause for this error is a lack of grounding to the transducer elements, particularly on the slider or stator.

7.2. **Sine/Cosine Balance Error**

This is a second harmonic error - it completes two cycles as the Inductosyn® travels through one cycle, see figure 12. It is caused by unequal amplification in the sine and cosine channels. The procedure for sine/cosine gain balance adjustment is given in section 4 above. The accuracy required for sine/cosine gain balance adjustment depends on the accuracy requirements of the system. For example: a 0.1% gain balance error will introduce a peak to peak cyclic error of one arc second for a 180 speed rotary system and a peak to peak cyclic error of 16 micro inches for a linear system with a 0.1 inch pitch.
7.3. **Cross Coupling Between Sine and Cosine Wiring**

This is a second harmonic error like the sine/cosine balance error of figure 12 - it completes two cycles as the Inductosyn® travels through one cycle. It differs from the sine/cosine balance error in its phasing - it peaks at 0, 90, 180 and 270 degrees compared with the balance error curve, which peaks at 45, 135, 225 and 315 degrees. This type of error is not usually a problem. It can be eliminated by correct shielding and by keeping all unshielded sections of wiring well separated and as short as possible, with the twist maintained as close to the termination point as possible.

7.4. **Fourth Harmonic Errors**

In this case the error curve completes four cycles as the Inductosyn® travels through one cycle. It is caused by a non-linearity in the preamplifier or, more likely, by over driving the excitation amplifier so that the peaks of the excitation signal are clipped. The converter is very insensitive to this type of signal distortion. This type of error is very unusual.