

Subject: <b>Signal Conditioning for Temperature and Other Nonlinear Applications</b>	Initial Release Date: 9/1/93	Revision Date: 12/26/96	Revision: A
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## 1. Purpose

This Product Information Note describes how AMETEK/Dixson's bargraph products can be used to measure non-linear input variables such as temperature sensors and thermocouples which are inherently non-linear, and fluid levels in irregularly shaped containers. Included is a description of how to use the AMETEK/Dixson Programming and Calibration Software package to generate linearization coefficients which the bargraph can use to compensate for nonlinear inputs.

## 2. AMETEK/Dixson Programming and Calibration Software

The AMETEK/Dixson Programming and Calibration Software package (programming software) is a powerful program. It contains accurate data tables to linearize thermocouple and RTD signals, the special case of square root extraction for flow measurement, and other nonlinear inputs. It is available by ordering P/N 239-53033.

### 2.1 Definitions, Overview of Linearization

*Linear* is defined as "...arranged in a straight line". A linear function is a mathematical equation that represents a straight line, in one dimension, of the first order. Many sensors produce an output signal that is nonlinear with respect to the process it is measuring. Thermocouples and pressure transducers are two common examples. Some sensors produce a linear output but the environment they are placed in dictates that linearization is needed to obtain a desired final result. Tank level applications are an example, with the desired result being a reading in gallons, and the shape of the tank causing the non-linearity.

*Polynomial* is defined as "...consisting of or containing many terms, or pieces". A polynomial equation is an equation of greater than the first order. An eighth order polynomial has a total of nine terms. The programming software uses an eighth order polynomial equation to approximate the nonlinear function it is given to linearize. It is accurate and adds very little error to the final desired result. A discussion of the error added by the linearization is given in Section 4.2.

### 2.2 Temperature Sensors

The programming software comes with pre-stored coefficients for type E, J, K, T thermocouples and 100-ohm RTDs. These coefficients were derived from NIST data for the mentioned type. The range spans for the various types are shown in the following table:

Type E Thermocouple	-100°C to +1000°C
Type J Thermocouple	-18°C to +760°C
Type K Thermocouple	-18°C to +1,370°C
Type T Thermocouple	-160°C to +400°C
RTD (100 ohm Platinum)	-200°C to +850°C

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### 2.3 Square Root Extraction

The programming software can provide the square root extraction required to linearize differential pressure devices. As with the thermocouple coefficients, this eliminates the need to assemble a data table and generate coefficients—it is simply a menu selection. The use of differential pressure devices as an inferred measurement of a liquid's flow rate is well known. Differential pressure flow meters are by far the most common units in use today. Differential pressure devices (*head meters*) include orifices, venturi tubes, flow tubes, flow nozzles, pilot tubes, elbow-tap meters, target meters, and variable-area meters. If you are using one of these types of meter, use the Square Root selection of the Non-Linear pull-down menu.

### 2.4 Other

Many other types of signals could require linearization. Some of the most common examples are storage tanks. Most level sensors have linear outputs with respect to the depth of material in the tank, and it is the desire to display the material volume in gallons, liters, etc., that brings the shape of the tank into the picture. It is the shape of the tank that induces the non-linear effect in a volume reading. The following section works through one linear and two nonlinear storage tank applications. The steps contained apply to any linearization that is required.

## 3. Typical Applications—Tank Level Indication

Figure 1 illustrates a cylindrical tank having a flat top and bottom and holding 100 gallons. If a 4/20 mADC linear level sensor were installed in this tank, the sensor output would be directly proportional to the tank volume, and no linearization would be required. The form of this first order linear equation is:  $Y = mX + b$ , where

**Y** is the vertical axis (gallons)

**X** is the horizontal axis (sensor output in DC milliamperes)

**m** is the slope of the line

**b** is the Y intercept when X is at 0.0 mADC

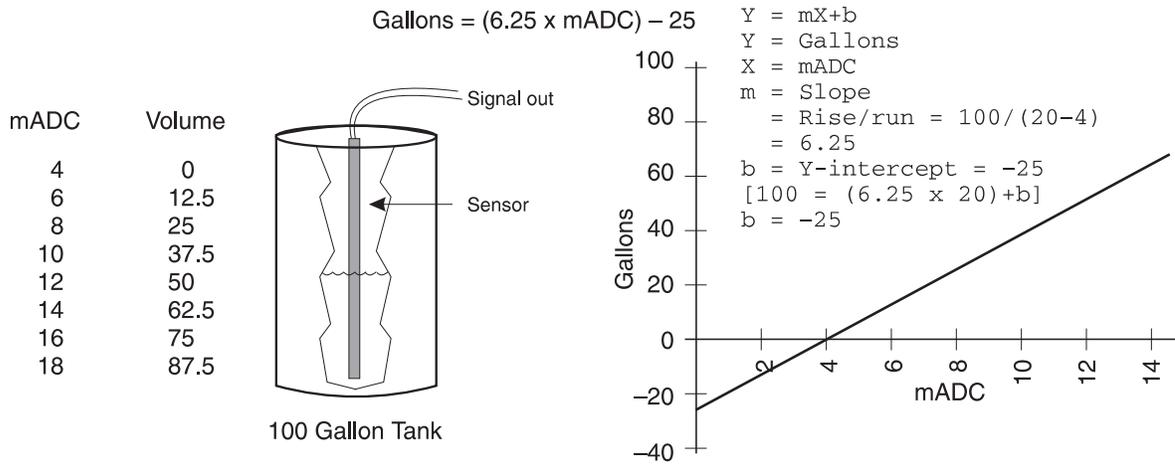
This relationship is shown graphically in Figure 1. Each milliampere change in the sensor's output equals exactly 6.25 gallons, and the relationship is linear.

Figure 2 shows a cylindrical tank with a conical bottom and a spherical top. If the same linear sensor were placed in this tank, the relationship of tank volume to sensor output would be nonlinear. As the tank fills, the sensor output increases faster than the volume at first, then rises linearly as the cylindrical section fills, then increases as the spherical section at the top fills. This is shown graphically in Figure 2. This tank is a candidate for linearization. You cannot write a first order linear equation that describes the graph shown in Figure 2, but you can write a polynomial equation that would approximate the curve very closely.

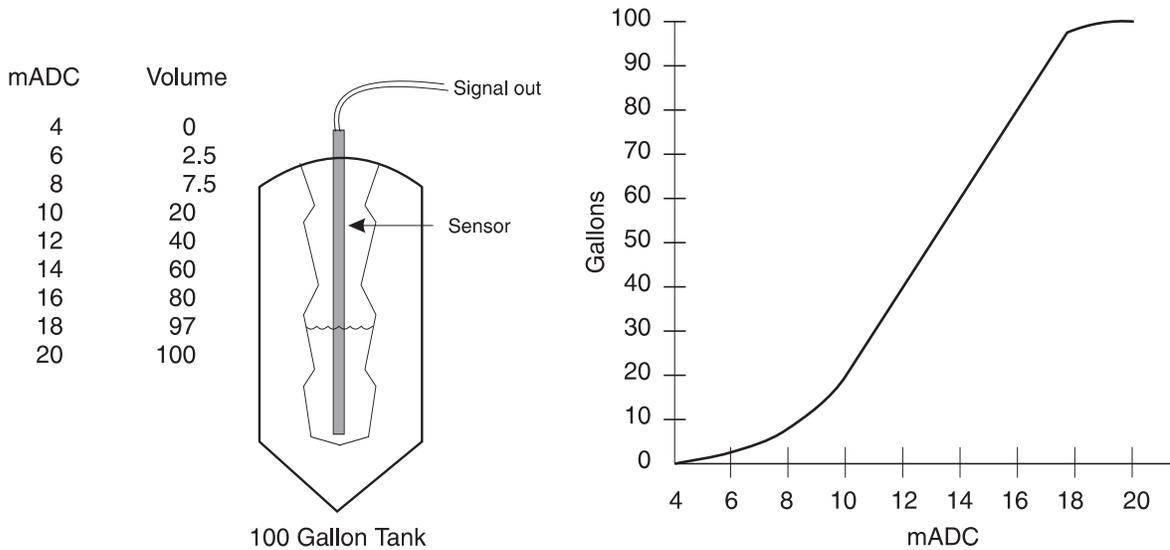
Figure 3 shows a cylindrical tank with spherical ends laying on its side. The equation under the tank calculates the tank volume in liters at any given liquid height in feet from the bottom of the tank. Using a linear sensor, the data table in Figure 3 describes the nonlinear relationship of the sensor output to the tank volume. Once the data in Figure 3 is collected (either by mathematically

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deriving it or by actually measuring it), the linearization process using the programming software can begin.

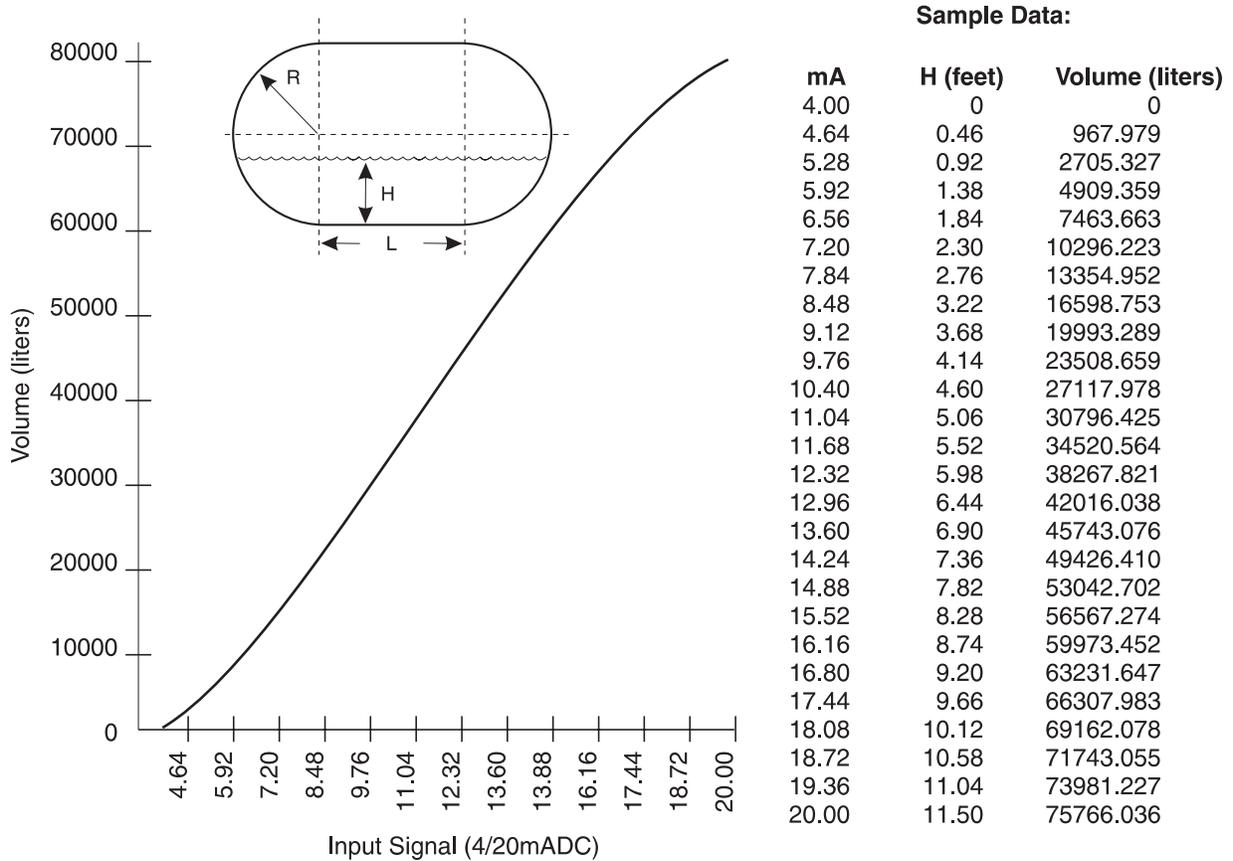


**Figure 1** Linear output example



**Figure 2** Nonlinear output example

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$$\text{Volume (liters)} = \{ (R^2) \text{ACOS}[(R-H)/R] - (R-H) \cdot \text{SQRT}[2R(H-H^2)] \} L \cdot 28.317$$

$$= \{ (6^2) \text{ACOS}[(6-H)/6] - (6-H) \cdot \text{SQRT}[12(H-H^2)] \} 24 \cdot 28.317$$

**9 Coefficients:**

- A = 34900.02
- B = -167411.10
- C = 330755.70
- D = 354053.20
- E = 226451.60
- F = -95686.61
- G = 31298.69
- H = 1382.66
- I = 0.7467

H = Height of liquid  
 R (6 feet) = Radius of tank end  
 L (24 feet) = Length of tank  
 28.317 = Conversion from cubic feet to liters

$$\text{Vol} = 34900.02X^8 - 167411.2X^7 + 330755.7X^6 - 354053.2X^5 + 226451.6X^4 - 95686.61X^3 + 31298.69X^2 + 1382.66X^1 - 0.7467$$

**Figure 3** Nonlinear tank application

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#### 4. Using the Programming and Calibration Software for Linearization

The programming software can accept a data table as an input and derive the coefficients for the eighth order polynomial it uses to approximate nonlinear functions. The data table must be in the same directory where the programming software resides. It must be an unformatted ASCII text file, (no page breaks, margins, etc.) The numbers in each data pair must be separated by at least one space. The first number of each pair is the input signal value, and the second number is the desired reading.

The Pro-Series digital display is a four-digit display, and displays an integer value only—any decimal placement is forced. The table in Figure 3 shows that the capacity in liters contains more digits than can be displayed on the bargraph's digital display. The total capacity must therefore be truncated to four digits and a multiplier placed on the scale plate artwork to indicate total capacity. In the example, the highest number that can be displayed is 7576, so the scaleplate multiplier would be X10. The contents of the text file would then appear as follows:

```
4.00      0.0
4.64      96.7979
5.28      270.5327
5.92      490.9359
          etc.
          etc.
19.36     7398.1227
20.00     7576.6036
```

The data file must contain at least 12 data pairs and not more than 1500 data pairs. It can be created by a text editor, a word processor, a spreadsheet program, or a database program. As long as it is unformatted ASCII text, the programming software will accept the file as an input. Generate the coefficients as follows:

1. Create the data file and save it in the directory where the programming software resides.
2. Start up the programming software.
3. Select Inputs > Input Type > Non-Linear. A dialog box will appear that allows you to select either Data File or Coefficients.
4. Select Data File by using <Tab> to enter this dialog box. Once Data File is selected, a box will open for the file name.
5. Type the name of the data file including its extension (example: tank01.txt).
6. Use <Tab> to highlight the OK box and press <Enter> to generate the coefficients.
7. To view the coefficients, select File > View.
8. Select/adjust any other desired parameters (i.e., setpoints, digital display, bar start, communications and others) and save the configuration by selecting File > Save.

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**Note** - *The span of the unit is set as two numbers using Options > Digital Display. During the linearization process, the programming software also sets the scaling.*

9. Download the configuration information to the bargraph using the Download menu.

Instructions for using programming software can be found in its on-line Help screens. Once the unit resets, it can be tested with a calibrator or an actual signal input to verify the linearization is correct. Figure 3 contains the eighth order polynomial equation and the coefficients that would be generated by this example.

#### 4.1 Entering Linearization Coefficients Directly

You can bypass the internal coefficient generator and enter the nine coefficients. This might be done if the coefficients are generated by means other than the programming software, or if the coefficients are known but the process that generated them is no longer available. To enter the coefficients directly:

1. Select Inputs > Input Type > Non-linear.
2. Tab to the Linearization dialog box.
3. Select Coefficients. A dialog box will open allowing the 9 numbers to be entered. "A" is the coefficient for the 8th order term, "B" for the 7th, and so on, with "I" being the Y intercept.

#### 4.2 Error Discussion

Since a polynomial curve fit is a close approximation, a small error exists in the resultant reading. In the above example, the worst case error is 0.0298% of the span and the typical error is less than 0.01% of the span. These induced error percentages are typically less than the accuracy of the transducer and often less than the accuracy that can be read on the instrument and are thus considered insignificant. In almost all instances, error is less than with alternative systems.

Errors are more prominent at the less linear parts of the curve. Various techniques can be applied to the data set to minimize these errors if they are considered significant. One method is to significantly increase the number of data pairs near a "troublesome" part of the curve.

#### 4.3 Conclusion

The above example of tank linearization can be applied to virtually any nonlinear signal. Careful collection of data or generation of a data table is key to an accurate curve fit. The more data pairs, the better the curve fit, and the less error.

## 5. Technical Support

All AMETEK/Dixson bargraph products are supported by the AMETEK/Dixson Bargraph Service Department. The Service Department can be reached at (970) 244-1245, Monday through Thursday from 7:00 a.m. to 5:30 p.m. MST, and on Friday from 7:00 a.m. to 3:30 p.m. You may also leave a message at the following E-mail address: [info@ametekdixson.com](mailto:info@ametekdixson.com).