Investigate Calibration Methods for Pressure Transmitters

Jiaoyan Wang\textsuperscript{1,2} and Haining Zhang\textsuperscript{1,3}
\textsuperscript{1}School of Electronic and Information Engineering, Xi'an University of Technology, Weiyang District, Xi'an, Shaanxi Province
\textsuperscript{2}Email: 2119962948@qq.com
\textsuperscript{3}Email: zhn1964@163.com

Abstract. Pressure transmitter\cite{1-4} refers to a pressure sensor whose output is a standardized signal. The default memory value of the memory used to store the adjustment information in the internal signal conditioning chip is unknown, so the input and output curves of the pressure transmitter are unknown. The pressure transmitter must be calibrated to adjust the pressure transmitter input and output curves to standard input and output curves. Therefore, this paper studies a calibration method of the current output type pressure transmitter pressure based on the programmable gain amplifier PGA308. The method uses the average slope method to fit the pressure transmitter output output curve, which can realize the calibration of the pressure transmitter. The calibration accuracy can reach 0.0063\%, and the calibration rate can reach 9.9 seconds/piece.

1. Introduction
A pressure transmitter refers to a pressure sensor whose output is a standardized signal. Standardized signals refer to the form of physical quantities and the range of values that conform to internationally standardized signals. For example, the analog DC current of 4-20 mA and the gas pressure of 20-100 kPa are all common remote transmission standard signals. In addition, domestic pressure transmitters sometimes use DC current 0-10mA as the output signal. Regardless of the physical, chemical, and biological parameters of the pressure transmitter input variable, and regardless of the input signal value, the information after the transmitter must be included in the standard signal. With a uniform output signal form and numerical range, it is easy to combine pressure transmitters and other instruments into a detection system or adjustment system\cite{5-7}. No matter what instrument or device, as long as there is the same standard input circuit interface, the pressure transmitter output information can be obtained, and then the pressure transmitter input variable information can be obtained. The uniform output signal standard of the pressure transmitter improves the compatibility and interchangeability of the entire system and is easy to use\cite{8}.

2. Pressure Transmitter Calibration Principle
2.1. System Block Diagram
The main components of the calibration system include the host computer, the lower computer hardware circuit, the pressure controller, and the multimeter. The host computer communicates with the lower position machine, the pressure transmitter, the multimeter and the pressure controller through four 232 serial ports. After the automatic calibration software system is installed in the upper computer, the 32-channel pressure transmitter can be automatically calibrated. The hardware circuit of the lower computer is connected with the host computer through the 232 serial port, and the 32-way sign channel is freely switched. The protocol conversion module of the lower computer part realizes
the communication between the upper computer and the pressure transmitter. The pressure controller communicates with the host computer through the 232 serial port, receives pressure control information, and controls the pressure input pressure of the pressure transmitter. The multi-meter communicates with the host computer through the 232 serial port, receives the multi-meter control information, and can send the collected pressure transmitter output current data to the upper computer.

![Diagram of calibration system overall design block diagram.](image)

**Figure 1.** Calibration system overall design block diagram.

### 2.2. Calibration Principle

The pressure transmitter automatic calibration system provides digital calibration of zero-point migration and range migration for current output type pressure transmitters. Zero-point migration refers to the use of some adjustment method to cause changes in the output value of the pressure transmitter when the transmitter is operating at the lower limit of the working range. Range shifting refers to the use of some means to cause a change in the current output range of the pressure transmitter. The principle of pressure transmitter calibration is to measure the standard value of the pressure transmitter output in its working range as the metric ruler, measure the original output value of the pressure transmitter to be calibrated in its working range, and calculate the pressure to be calibrated. The value of zero migration and range migration required by the transmitter, the calculation result is written into the signal conditioning chip inside the pressure transmitter, and finally the input and output curve and pressure transmitter of the pressure transmitter to be calibrated in its working range are realized. The standard input and output curves are consistent and the calibration is completed [9-12].
2.3. Determination of the Original Input and Output Curve of the Pressure Transmitter

The pressure transmitter is a linear sensor whose input and output curves can be expressed by a linear equation \( y = kx + b \) [13]. In this paper, the average slope method [14] is used to determine the original input and output curves of the pressure transmitter. The zero output of the output curve is \( b \), which is

\[
b = \frac{\sum_{i=1}^{n} y_{i1}}{n},
\]

and the slope of the output curve

\[
k = \frac{\sum_{i=1}^{n} (y_{i2} - y_{i1})}{n \cdot (V_{\text{max}} - V_{\text{min}})} = \frac{\sum_{i=1}^{n} y_{i2} - \sum_{i=1}^{n} y_{i1}}{n \cdot (V_{\text{max}} - V_{\text{min}})} = \frac{y_2 - y_1}{(V_{\text{max}} - V_{\text{min}})}
\]

(1)

Where \( n \) denotes the number of measurement points, \( \bar{y}_1 \) denotes the mean value of the current output when the pressure transmitter operates at the lower limit of the working range \( V_{\text{min}} \), and \( \bar{y}_2 \) denotes the mean value of the current output when the pressure transmitter operates at the upper limit of the working range \( V_{\text{max}} \).

2.4. Determination of Standard Input and Output Curves of Pressure Transmitter

Take the coordinates \( (V_{\text{min}}, I_{\text{st,min}}) \), \( (V_{\text{max}}, I_{\text{st,max}}) \) of the two points on the standard output curve of the pressure transmitter, and substitute the coordinates into the \( y = kx + b \)

\[
k_{\text{st}} = \frac{I_{\text{st,max}} - I_{\text{st,min}}}{V_{\text{max}} - V_{\text{min}}}
\]

(2)

Bringing the calculation results of the coordinates \( (V_{\text{max}}, I_{\text{st,max}}) \) and \( k_{\text{st}} \) into the formula \( y = kx + b \) is

\[
b_{\text{st}} = V_{\text{max}} - k_{\text{st}} I_{\text{st,max}}
\]

(3)

Where \( (I_{\text{st,min}}, I_{\text{st,max}}) \) is the standard output range of the pressure transmitter.

From this, the standard output range of the pressure transmitter can be determined.

2.5. Calculation of Zero Point Migration and Range Migration

The input and output curves of the pressure transmitter to be calibrated are

\[
y = k_{or} x + b_{or}
\]

(4)

Zero migration is \( b_{er} \), range migration is \( k_{er} \), then

\[
b_{er} = b_{st} - b_{or}
\]

(5)

\[
k_{er} = k_{st}/k_{or}
\]

(6)

2.6. Implementation of the Calibration Method

After determining the original input and output curve and standard input and output curve of the pressure transmitter, the zero point migration and range migration can be obtained by equations (5) and (6), and finally the zero point migration and range migration data are stored to the pressure transmitter. The internal signal conditioning chip PGA308 chip internal OTP memory, to complete the calibration.

The PGA308 chip company provides a specific distribution of zero migration and range migration:
Among them, zero migration involves parameters $V_{\text{Coarse}_{-}\text{Offset}}$, $V_{\text{Zero}_{-}\text{DAC}}$, GI, range migration involves parameters GI, GD, GO, and $V_{\text{IN}}$ refers to the original output signal of the pressure transmitter, only the calculation formula (7). The unknown parameter is written and the calculation result is written into the corresponding register of the signal conditioning chip PGA308 to complete the calibration [15-16].

The voltage and current conversion formula is:

$$I_{\text{OUT}} = \frac{V_{\text{IN}}}{R} \times 100$$

(9)

Therefore, the implementation of the calibration method is divided into the following steps:

1) The input parameters of the control pressure transmitter are the working range lower limit and the upper limit pressure $V_{\text{MIN}}$ and $V_{\text{MAX}}$, respectively, and the pressure transmitter output current data $I_{\text{OUT}_{-}\text{MIN}}$, $I_{\text{OUT}_{-}\text{MAX}}$ are collected, and converted into $V_{\text{IN}_{-}\text{MIN}}$, $V_{\text{IN}_{-}\text{MAX}}$ according to the formula (9). The pressure transmitter's original output signal range is $(V_{\text{IN}_{-}\text{MIN}}, V_{\text{IN}_{-}\text{MAX}})$.

2) By substituting $V_{\text{IN}_{-}\text{MIN}}$, $V_{\text{IN}_{-}\text{MAX}}$ into equations (5) and (6), the zero migration $b_{\text{er}}$ and the range migration $k_{\text{er}}$ can be calculated. The calculation result is then assigned to each coefficient in equation (7). The PGA308 chip allocates the range migration $k_{\text{er}}$ to the three parameters GI, GD, GO, namely $k_{\text{er}} = GI \times GD \times GO$. Where GI data ranges from 4, 6, 8, 12, 16, 32, 64, 100, 200, 400, 600, 800, 960, 1200, 1600; GD ranges from 0.333333333 to 0.999999824; GO takes The values range from 2, 2.4, 3, 3.6, 4, 4.5, 6. Therefore, the allocation process of range migration first takes $GD = 0.666666666$, traverses all values of GI, GO, makes the error $er = |b_{\text{er}} - GD \times GI \times GO|$, finds the distribution mode of GI, GO with the smallest error $er$, determines the value of GI, GO; then finds $GD = b_{\text{er}}/(GI \times GO)$, completes the range allocation of the migration. $V_{\text{Coarse}_{-}\text{Offset}}$ can be calculated according to equation (8). Calculate the standard output voltage of the pressure transmitter at the upper limit pressure of its working range and the previously calculated pressure transmitter to be calibrated under the same pressure condition, and substitute the original output voltage $V_{\text{IN}_{-}\text{MAX}}$ into equation (7).

$$V_{\text{Zero}_{-}\text{DAC}} = \frac{V_{\text{OUT}}}{GD \times GO} - (\text{mux}_{-}\text{sign} \times V_{\text{IN}_{-}\text{MAX}} + V_{\text{Coarse}_{-}\text{Offset}}) \times GI$$

(10)

According to the preservation method of the internal parameters of the PGA308 chip, the result obtained in the previous step is converted into the corresponding hexadecimal data, and then sent to the pressure transmitter signal conditioning chip PGA308 to complete the calibration.

3. Experimental Data and Analysis

3.1. Experimental Conclusions and Data Analysis

Apply the pressure calibration system to the actual calibration work. First, perform a field calibration on a group of pressure transmitters. The calibration results are shown in Table 1:
Table 1. Calibration Results Table.

| Serial | GainTotal | GI  | GainDAC | GO  | CoarseOffset | ZeroDAC |
|--------|-----------|-----|---------|-----|--------------|---------|
| 1      | 418.646789| 200 | 0.697744648 | 3 | 0            | 0.458266783 |
| 2      | 433.2121711 | 200 | 0.722020285  | 3 | -0.0009566 | 0.934498049  |
| 3      | 424.074864 | 200 | 0.70679144  | 3 | -0.0009566 | 0.935072126  |
| 4      | 453.6565711 | 200 | 0.630078571  | 3.6 | 0      | 0.445086153  |
| 5      | 437.0461607 | 200 | 0.728410268 | 3 | 0.000956598 | -0.019126086 |
| 6      | 427.626948 | 200 | 0.656426317  | 3.6 | 0.000956598 | 0.914719338  |

3.1.1. Error analysis

During the on-site debugging process, the current output data of 50 sets of calibration pressure transmitters were collected as samples. The maximum reference error of the calculator is meter maximum reference error=(maximum absolute error in the range/range)*100%, and the maximum reference error [17] sample was obtained, as shown in Table 2:

Table 2. Maximum reference error statistics.

| Serial | Maximum reference error | Serial | Maximum reference error | Serial | Maximum reference error | Serial | Maximum reference error |
|--------|-------------------------|--------|-------------------------|--------|-------------------------|--------|-------------------------|
| 1      | 0.005952%               | 14     | 0.004762%               | 27     | 0.003968%               | 40     | 0.005556%               |
| 2      | 0.005952%               | 15     | 0.003175%               | 28     | 0.003571%               | 41     | 0.003571%               |
| 3      | 0.008730%               | 16     | 0.007540%               | 29     | 0.003968%               | 42     | 0.003968%               |
| 4      | 0.006746%               | 17     | 0.006349%               | 30     | 0.004365%               | 43     | 0.002381%               |
| 5      | 0.005952%               | 18     | 0.004762%               | 31     | 0.009127%               | 44     | 0.003571%               |
| 6      | 0.005952%               | 19     | 0.004762%               | 32     | 0.007540%               | 45     | 0.005159%               |
| 7      | 0.009921%               | 20     | 0.005159%               | 33     | 0.005556%               | 46     | 0.008730%               |
| 8      | 0.009524%               | 21     | 0.004365%               | 34     | 0.005952%               | 47     | 0.008730%               |
| 9      | 0.006746%               | 22     | 0.002778%               | 35     | 0.004762%               | 48     | 0.008730%               |
| 10     | 0.009524%               | 23     | 0.002381%               | 36     | 0.005556%               | 49     | 0.009127%               |
| 11     | 0.009524%               | 24     | 0.004762%               | 37     | 0.004762%               | 50     | 0.007937%               |
| 12     | 0.008333%               | 25     | 0.003968%               | 38     | 0.005556%               |
| 13     | 0.001984%               | 26     | 0.003571%               | 39     | 0.003571%               |

The sample mean value is 0.00628%, the sample standard deviation is 0.002501%, the confidence is 95%, and the confidence interval is (0.0058%, 0.0068%), that is, 95% confidence is determined, and the calibration accuracy is (0.0058%, 0.0068). Within the %) interval, the expected accuracy of 0.0063% was achieved. It can be proved that the pressure transmitter automatic calibration system can achieve the accuracy target proposed in the design.
3.1.2. **Calibration rate analysis**

Through the investigation of the calibration production line, the time statistics table for each 100 calibration pressure transmitters for each calibration workbench is shown in Table 3:

**Table 3. Automatic calibration system calibration time statistics table.**

| Numbering | Number of calibrations $y_n$ | Calibration time $H_n$ | Calibration rate |
|-----------|-------------------------------|------------------------|------------------|
| 0         | 100                           | 323                    | 10.1             |
| 1         | 100                           | 314                    | 9.8              |
| 2         | 100                           | 317                    | 9.9              |
| 3         | 100                           | 317                    | 9.9              |
| 4         | 100                           | 317                    | 9.9              |
| 5         | 100                           | 326                    | 10.2             |

Pressure transmitter calibration system calibration of a pressure transmitter average time is 

$$
\overline{T_n} = \frac{1}{n} \sum_{n=0}^{N-1} \frac{H_n * 3600}{y_n},
$$

substituting the data in Table 3 gives the second/number.

4. **Summary**

The calibration method of the pressure transmitter is based on the average slope method of the current output type pressure transmitter of the programmable gain amplifier PGA308. By fitting the input and output curves of the pressure transmitter, the calibration is achieved, and the calibration accuracy is 0.0063%, and the calibration is achieved. The rate is 9.9 seconds per one.

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6. **References**

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