Design of Portable Air Purge Level Transmitter with Built-in Calibration Feature

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Abstract. In almost all the process industries level is the prominent process parameter which is being monitored and controlled. For level measurement a wide variety of level sensors are available. For level measurement of chemically corrosive liquids or liquids containing suspended solids, specific sensors are used. In such applications, the direct contact of sensor with the fluid is avoided. Air purge or bubbler pipe is the most suitable level measurement method in such cases. In this method, compressed air is forced through the bubbler pipe which is placed in the level measurement tank. This compressed air/gas emerges from the other end of the tube in the form of bubbles. The pressure in the pipe is equal to the head pressure created by the height of liquid column in the tank. The conventional air purge level measurement method has limitations like lack of portability and non-electrical output. This also consumes more power, lacks in scheduled measurement and requires recalibration for the changes in the range. To overcome these limitations a novel portable programmable air purge level transmitter is designed in this paper. The designed system consists of an on board compressor to improve the portability. The electrical output is obtained using MEMS pressure sensor which is mounted on the top of the bubbler pipe. The electrical signal given by the MEMS pressure sensor is converted to standard output using Microcontroller and Signal Conditioning Unit. The system is made programmable using keyboard and display interface to microcontroller. Due to this recalibration and scheduled measurement is possible and this results in reduced power consumption.

1. Introduction

Liquid level measurement is an integral part of process industries like chemical industry, petroleum industry, fertilizer industry, food processing industry, etc. In process industries, there are many challenges in liquid level measurement due to hazardous environment [1]. Liquid level measurement techniques are classified as contact type and non-contact type [2]. The most commonly used contact type liquid level sensors are float type, air purge, differential pressure cell, capacitance probe. The conventional level sensing techniques are reliable and less expensive [3]. However, these sensors require for maintenance and the life span of these sensors is limited. Capacitive-level sensors are reliable, sensitive and simple in construction. So they are most commonly used [4]. However, frequent re-calibration is required for capacitance probe due to changes in temperature, density and dielectric media. Ultrasonic type is the most commonly used non-contact liquid level sensor owing to its simple construction [5]. But the readings are affected due to interference. Ultrasonic level measurement in narrow vessels like bore well
gives false reflections leading to incorrect readings. Due to complicated electronics this method becomes expensive.

For level measurement of chemically corrosive liquids or liquids containing suspended solids, direct contact of sensor with the fluid is avoided. Air purge or bubbler pipe is the most suitable level measurement method in such cases since in this method compressed air/gas is forced through the bubbler pipe which is placed in the level measurement tank. The back pressure in the bubbler pipe which is directly proportional to the level in the tank is measured by a pressure sensor in the developed system. Thus the pressure sensor thus does not come in direct contact with the fluid. Also due to purging of air, contamination of the probe due to the liquid having suspended solids is avoided. In such applications, if capacitance probe is used, then due to contamination of the probe the readings are affected. However in conventional air purge level measurement method there are some limitations like lack of portability, non-electrical output. This also consumes more power, lacks in scheduled measurement and requires re-calibration for change in range. To overcome these limitations a novel portable programmable air purge level transmitter is designed in this paper. The designed system consists of an on board compressor to improve the portability. The electrical output is obtained using MEMS pressure sensor mounted on the top of the bubbler pipe. The electrical signal given by the MEMS pressure sensor is converted to standard output using Micro-controller and Signal Conditioning Unit. The system is made programmable using keyboard and display interface to micro-controller. Due to this re-calibration and scheduled measurement is possible and this results in reduced power consumption.

2. Literature Review

The sensors used for liquid level measurement can be classified based on various parameters [5], [6], [7], [2]. Based on the measurement mode it can be classified as consistent or point esteem value. In consistent measurement mode the level is measured continuously using continuous level sensors. In case of point esteem value, the level is detected if it is below or above a specified point by the point level sensor [4]. The level sensors can also be classified as contact or non-contact type. The level sensors classified based on the principle of application are ultrasound, capacitive, optical, Vibrating or Tuning Fork, Conductivity or Resistance, Float Switch. Most of these sensors are invasive and are affected by various elements in the environment. A remote grounded capacitive sensor for the liquid level measurement was designed by Reverter et al. [8]. This system was based on contact type. Khan et al. [9] have designed non-contact capacitance type liquid level transducer with low cost. To measure oil level Lu et al. [10] have developed a sensor based on inductive and capacitive principle. K. V. Santhosh et al has designed Liquid Level Measurement instrument Using Multi sensor Data Fusion [11]. Level transmitter using force resistive sensor was presented by Anamika Lata et al. [3].

As seen from the literature survey, the existing methods are based on capacitive sensors, ultrasonic sensors, potentiometric sensors. The level transmitters are generally calibrated for a fixed SPAN. The accuracy of the output current from these transmitters is specified for % of Full scale (F.S.). Most of the industrial applications demand accuracy of around 1% of F.S. If the full span of level is not used for measurement, then the span of output reduces and hence the overall accuracy degrades. Capacitive sensors are susceptible to changes in dielectric constant because of ambient temperature variation, chemical compositions and radio frequency interference (RFI). These sensors are affected by clogging problem. Ultrasonic sensors cannot be used in the tanks having narrow cross sectional area like tube-well. The side wall of the well reflects the ultrasonic signal back to the receivers. It is also required to fit the sensor head inside the tank. The potentiometric sensors need mechanical arrangements for tracking the level in tank. It is generally used with float and counter balancing weight. This sensor has sliding contact hence it has mechanical ware and tare problem. The sensor electrically represents
Thevenin’s voltage source whose output resistance changes according to the level. This affects the accuracy of measurement.

Out of all these sensors the bubbler tube is the simplest and a low cost solution to the level measurement. But these sensors are not portable and require frequent calibration. To address these issues we have designed Portable Programmable Air Purge Level Transmitter in this paper.

3. System Details
The detailed block diagram of the developed system is shown in Figure 3. The developed system consists of measurement unit, signal processing unit with user interface and standard transmission unit. The MEMS pressure sensor senses the back pressure in the bubbler pipe. The output signal of this sensor is conditioned in the signal conditioning block and is given to the Micro-controller for further processing. The signal is then converted it to standard industrial current range of $4 - 20\text{mA}$.

![Figure 1. Block Diagram of Developed System](image)

3.1. Static pressure measurement unit
Measurement unit consists measuring tank, bubbler pipe, on-board compressor with driver circuit and MEMS pressure sensor MPXV10. Measuring tank is used for storing liquid of
which the level is measured. A PVC pipe is used as a bubbler pipe on which the back pressure
sensor and the compressor are mounted. The advantage of using PVC pipe is that it is corrosion
resistant. A purge gas is normally an air supply used specifically in areas which are susceptible
to contamination or an oxidative reaction with the medium. Compressed air is used as the purge
gas in our system. Nitrogen gas can also be used in case of flammable liquids. In the developed
system a diaphragm compressor is used which is as shown in Figure 2. It is commonly used for
domestic aquariums as an aerator. It is a positive displacement type diaphragm pump. It is
also deployed in wrist type blood pressure monitor. The specifications of the same are given in
the Table 1. The compressor is mounted on top of the bubbler pipe in order to pump air into
it. Compressor is driven by a regulated power supply built using IC TIP 122.

![Figure 2. Diaphragm compressor](image1)

| Sr. No. | Parameter                | Specification |
|---------|--------------------------|---------------|
| 1.      | Rated voltage            | 3V            |
| 2.      | Voltage range            | 2.0 to 3.2 V  |
| 3.      | Current consumption      | below 450 mA  |
| 4.      | Highest pressure         | Above 47kPa   |

MPXV10 series back pressure sensor is shown in Figure 3. MPXV10 is silicon piezo-resistive
pressure sensor. Its output voltage changes with changes in the back pressure which is due to
changes in the level. Its differential pressure range is 0 to 10kPa. The sensor is powered with a
regulated 5V DC source. This sensor is mounted on the bubbler pipe which is connected to the
compressor using T-connector. The back-pressure in the bubbler-pipe increases proportionally
with the level. The back pressure is equal to the height of a liquid column. This static back
pressure ($P$) is related to the level ($h$) in the tank by the equation 1.

$$ P = h \rho g $$  \hspace{1cm} (1)

where $\rho$ is the density of the liquid and $g$ is the gravitational acceleration. The output voltage
signal obtained from pressure sensor is in milli volt range. The signal is amplified to match the
further circuit. Instrumentation amplifier AD620 is used to amplify the signal. Gain (G) of
AD620 is set using RG resistor connected between pin 1 and 8 as shown in Figure 4. The output
of AD620 is connected to SPAN and ZERO circuit as shown in Figure 5 to provide output as
0-5V.
3.2. Signal Processing unit with user interface

The signal processing unit consists of ATmega8535 micro-controller, LED Display and Keyboard. Microcontroller ATmega8535 is the heart of the system which acts as the signal processor. The system has two parts namely indicator section and current transmitter section. These sections are controlled by the microcontroller. The microcontroller performs mapping of input level range and the output current of 4 – 20mA. The sensor-signal conditioner drives the ADC of controller. The analog signal from the measuring unit is converted into digital form using ADC and is given to micro-controller. We have used inbuilt 8 channel, 10 bit analog to digital converter of ATmega8535 micro-controller. The micro-controller processes the ADC Data. It is also responsible for synchronization of operation of various devices like LED display, keyboard, V to I converter connected to the system. 3-digit seven segment LED displays are used for indicating the liquid level in range of 0 to 100%. The system is provided with user-friendly pair of keys on-board. The keys are used to calibrate and set the user defined range of measurement. Thus, the display device in conjunction with the keyboard enables the operator to set the span and zero values for calibration.

The beauty of this system is that, it can be calibrated for any span of input level just by clicking the ZERO and SPAN keys. The calibration counts are stored in to EEPROM of the controller hence, the system holds the calibration even in case of power failure. The analog signal from the measuring unit is converted into digital form using ADC and is given to microcontroller. We have used inbuilt 8 channel, 10 bit analog to digital converter of ATmega8535 micro-controller. The micro-controller processes the ADC Data. It is also responsible for synchronization of operation of various devices like LED display, keyboard, V to I converter connected to the system. 3-digit seven segment LED displays are used for indicating the liquid level in range of 0 to 100%. The system is provided with user-friendly pair of keys on-board. The keys are used to calibrate and set the user defined range of measurement. Thus, the display device in conjunction with the keyboard enables the operator to set the span and zero values for calibration.

3.3. Standard Current Transmission Unit

The developed system is not only a level indicator but also a level transmitter. The standard transmitter output of 4 – 20mA is generated using filtering and V to I converter circuit. The digital values corresponding to 0 and 100% of level in the tank are used to drive the internal pulse width modulator (PWM) of ATmega8535. The PWM output signal from ATmega8535 is averaged by using a passive low-pass filter. Then output is then buffered and scaled to drive the current booster. The boosted 4 – 20mA output is provided as a process variable to various process controllers. Figure 6 shows the detailed circuit diagram of standard current transmission unit. The current booster section of the system is implemented with non-inverting amplifier with
unity gain. The transmitter section uses 100Ω resistance as a loop-current sensing resistance. It makes voltage drop proportional to the output current. The same voltage drop is fed back to the booster amplifier. The PWM signal varies from 0 to 5V in 256 steps. But the required voltage drive for current booster varies from 0.4V to 2V (for 4 -20 mA with 100Ω R-sense resistance). The scaling is done by using pair of voltage buffers, which then drive the current booster. The boosted current output is sourced by transistor TIP 122 which is darlington transistor with current gain of 1000. The PCB design and fabrication of the developed system is carried out in-house in our laboratory. The photograph of the same is shown in Figure 7.

![Figure 6. Circuit diagram of Standard Transmission Unit](image)

### System Design Calculations

The heart of the system is the signal processing unit. It is based on ATmega 8535 microcontroller. It has 8-channel 10-bit Successive Approximation Register (SAR) type ADC. The
DAC is implemented by using 8-bit Fast-PWM module of the controller. The design calculations for 0-100 cm range are given below. The ADC has Vref of 5 V. Hence the least count is calculated as

\[ \frac{5V}{1023} = 0.004887V = 4.88mV/\text{step} \] (2)

The output of pressure sensor is amplified to match with the Vref = 5V. The ADC provides 1023 samples for full scale output of the sensor. The Pulse Width Modulator (PWM) module is driven from 0-100 count to produce proportional PWM signal. The basic PWM module is of 8-bit hence it provides 0-255 steps to produce 0-100% PWM signal. The averaging circuit connected at the output pin of PWM based DAC provides 0-5 V linear output. The basic accuracy of the DAC is calculated as

\[ \frac{1}{255} \times 100 = 0.392\% (\text{F.S.}) \] (3)

The current transmitter unit generates 0-100 % signal by producing 0.4 V to 2 V. It means that 0.4 V = 0 % which is converted to 4 mA (ZERO) and 2 V = 100 % converted to 20 mA (SPAN). The desired accuracy of the output current is 1% of F.S. The V to I converter is driven with an increment of 16 mV. The 100kΩ potentiometer in Figure 6 is adjusted to set 2 V.

\[ 2V - 0.4V = 1.6V \] (4)

\[ \frac{1.6}{100} = 0.016V = 16mV/\text{step} \] (5)

Hence the initial count of 25 in PWM unit produces 4 mA current.

\[ 2000mV/16mV = 125 \] (7)

Hence the final count of 125 in PWM unit produces 20 mA current. The above calculation shows that 2 V signal is required from DAC for 125 count in PWM but the actual output can be calculated as

\[ \frac{125}{255} \times 5V = 2.45V \] (8)

The ZERO of measurement = 4 mA hence the required DAC output is 400 mV. The SPAN of measurement = 20 mA hence the required DAC output is 2000 mV.

\[ 400mV/16mV = 25 \] (6)

Hence the initial count of 25 in PWM unit produces 4 mA current.

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The existing systems are permanently set to a fixed range thereby shortening the range which results in degradation in accuracy of output current. The results are shown in Table 2.

From comparison of graphs shown in Figure 9, it is clear that the output accuracy of current is maintained to 1% of F.S irrespective of the range. The calibration procedure for the transmitter is simple, screw-driver less and user friendly. It is done by clicking the keys namely ZERO and SPAN. The designed system can be programmed for min range of 10 cm as per following calculations with the same accuracy of 1% of F.S.:

ADC output = 4.88 mV/step Current output is in 100 steps Accuracy = 1% of F.S. 100 steps x 4.88 mV/step = 488 mV The Max. Output of sensor = 5000 mV at 100 cm 488/5000*100 = 9.76 cm can be rounded off to 10 cm.
Table 2. Observation of ADC count and signal conditioning output for 100 cm and 80 cm level

| Level in cm | ADC count | Signal conditioner output (mV) | PWM count for 0-100cm | PWM count for 0-80cm |
|-------------|-----------|-------------------------------|-----------------------|---------------------|
| 0           | 2         | 0                             | 24                    | 25                  |
| 5           | 51        | 248                           | 30                    | 31                  |
| 10          | 102       | 497                           | 36                    | 38                  |
| 15          | 152       | 741                           | 41                    | 44                  |
| 20          | 202       | 985                           | 45                    | 50                  |
| 25          | 256       | 1249                          | 50                    | 57                  |
| 30          | 306       | 1493                          | 54                    | 63                  |
| 35          | 357       | 1742                          | 61                    | 67                  |
| 40          | 410       | 2000                          | 66                    | 75                  |
| 45          | 462       | 2254                          | 69                    | 81                  |
| 50          | 509       | 2483                          | 75                    | 88                  |
| 55          | 560       | 2732                          | 79                    | 93                  |
| 60          | 615       | 3001                          | 85                    | 100                 |
| 65          | 666       | 3250                          | 89                    | 107                 |
| 70          | 715       | 3489                          | 96                    | 112                 |
| 75          | 765       | 3733                          | 102                   | 119                 |
| 80          | 820       | 4001                          | 105                   | 125                 |
| 85          | 870       | 4245                          | 110                   | -                   |
| 90          | 923       | 4504                          | 116                   | -                   |
| 95          | 974       | 4753                          | 120                   | -                   |
| 100         | 1022      | 4987                          | 125                   | -                   |

Figure 9. Graph of 100 cm and 80 cm PWM output

4. Experimentation and Observations
Various experiments were performed to calibrate and test the developed system. The system is designed to measure level in the range of 0 cm to 100 cm.
4.1. Compressor Testing
Here we tested the maximum voltage at which the compressor can be driven without much fluctuations in output. For this the level was maintained constant at 70 cm in the measuring tank. It is observed that at 3V, the output voltage of compressor is stable. Also according to this maximum voltage we calculated the maximum level which the transmitter can measure. The maximum drivable range of the compressor is tested by following procedure:

(i) Compressor attached to a pipe sealed at one end.
(ii) A pressure gauge attached to other end of pipe
(iii) Compressor supply voltage is adjusted to 3V to get stable output voltage.

The pressure observed on the pressure gauge was 0.7kg/cm² i.e. 6999.332mm of water column. This pressure corresponds to a level of approximately 7m of water column. Thus the Maximum range of drivable water column by the compressor is 7m.

4.2. Characterization of pressure sensor
Figure 8 shows the pin diagram of MEMS pressure sensor MPXV10. The output voltage of the pressure sensor is observed for minimum and maximum level in the measuring tank. The output voltage obtained for the given range was 25mV to 60mV.

4.3. Calibration of Signal Conditioning Circuit
The output of MEMS pressure sensor MPXV10 is signal conditioned to generate micro-controller compatible signal of 0V to 5V. Zero adjustment is done to get 0V for 25mV and span adjustment is done to get 5V for 60mV using the circuits shown in Figure 4 and Figure 5. The readings were taken for changing the level from 0 mm to 100 mm. Figure 10 shows the graph of the output voltage versus level. This 0V to 5V output voltage is given as an input to the inbuilt ADC of micro-controller 8535. The internal reference voltage for the ADC was 2.5V. Using the keyboard and display the system can be calibrated for different ranges of level.

4.4. PWM and V to I Circuit
The PWM section is used as a digital to analog converter (DAC) which is used to drive the current booster for 4 to 20 mA output. The basic accuracy of output current is designed for 1% of full scale. It means that the 4-20mA output has 100 discrete steps. It is a live zero system hence at 4mA, the PWM is proportional to 25 decimal count. And hence for 20 mA the PWM count is 125. The mapping of output current is done by referring to the ADC count from the
input process variable. In the proposed system the input process variable is level. The level signal is transformed into voltage signal by using MEMS pressure sensor.

Following steps are followed for testing of standard transmission unit:

(i) The pulse width modulator is loaded with 25 decimal count in its output control register (OCR).

(ii) The input voltage to current booster is measured. It is found that it is 0.4V and the output current is 4mA.

(iii) The pulse width modulator is loaded with 125 decimal count in its OCR.

(iv) The input voltage to current booster is measured. It is found that it is 2.0V and the output current is 20mA.

Figure 11 shows the Characteristic trend of the transmitter section. It is linear with slope of 0.16 mA/count.

4.5. Calibration and Testing Procedure of the Developed System

Testing of the whole set-up is implemented for two settings (100cm and 80cm) and in two phases namely calibration and performance testing.

4.5.1. Calibration for 100cm level

(i) The dip-tube is fixed in to the empty tank to set the 0% level by clicking the ZERO key on the circuit board shown in Figure 7. The display showed “0”.

(ii) The tank is filled with tap-water up to 100cm level. The 100% level is set by clicking the SPAN key shown in Figure 7. The display showed “100”

4.5.2. Performance testing for 100cm level

(i) The tap is opened to drain the water up to 50cm and the output current is measured which was found to be 12mA and the display showed “50”

(ii) The level in the tank is then varied by pouring and draining the water and the output current is measured and the display is observed.

4.6. Calibration for 80cm level

(i) The dip-tube is fixed in to the empty tank to set the 0% level by clicking the ZERO key on the circuit board shown in Figure 7. The display showed “0”.

(ii) The tank is filled with tap-water up to 80cm level. The 100% level is set by clicking the SPAN key shown in Figure 7. The display showed “100”

4.7. Performance testing for 80cm level

(i) The tap is opened to drain the water up to 40cm and the output current is measured which was found to be 12mA and the display showed “50”.

(ii) The level in the tank is then varied by pouring and draining the water and the output current is measured and the display is observed.
4.8. System setup testing for different liquids
The proposed system is tested for measurement of level in a fabricated calibration test set-up. There are three liquids used for testing the performance of the system. The results are as shown in Figure 12.

The proposed sensor can be used for measurement of level in a tank having narrow opening on the top. It can be used for acid, oil, water, lubricating oils etc. The output of the sensor dependent on the density of the subject liquid. Hence it is required to calibrate the system before use. The performance of the system is tested for Lubricating oil 20W40, tap-water and Diesel.

5. Conclusion
The performance of the system is tested on an experimental setup. It is found that the overall characteristic of the system is linear within ±1% accuracy. The system can be calibrated for range of 0-10cm to 0-100cm without degrading output current accuracy of 1% of F.S. The total current consumed by the system is 120mA at 12Volts. Hence, the overall consumption of the system is 1.4W which is substantially less. Due to low power consumption the system is operated on 12Volt batteries. The design and construction of the developed system is simple and is cost effective. The developed transmitter can be used for measuring level upto 7m. The system can be deployed for vessels having narrow openings. It will need opening just to insert the dip-tube. The system is made programmable using keyboard and display interface to micro-controller. It can be used for corrosive liquid by using SS316 grade tube. The system has an on-board indicator. The system can be safely used in hazardous area. The air is continuously flooded through the system hence the pressure sensor does not expose to the corrosive fumes from the liquid. The system is portable due to on board compressor. Due to this re-calibration and scheduled measurement is possible and this results in reduced power consumption. It is sensitive to specific gravity of the subject liquid. The system cannot be used for powder material. It cannot be used for viscous and sticky liquids. There is a scope for future development. The system has a micro-controller hence can be adapted to IoT platform for remote monitoring. The proposed system can be used for measurement of Specific gravity of the subject liquid by inserting the dip-tube at a fixed level. SD-card can be provided for data logging.
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