Application Note

NOVOSENSE

NSPGD1 Enables High-precision Liquid Level Measurement

AN-12-0004

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ABSTRACT

The function of water level sensor is to monitor the change of liquid level and control the liquid level. Water level sensor is used in many household appliances and equipment, such as washing machine, coffee machine, dishwasher, water dispenser, water heater, etc. With the development of intelligent household appliances, the control accuracy of water level sensor has higher requirements. NSPGD1 series pressure sensor is a high-precision gauge pressure sensor product launched by NOVOSENSE, which can be used for non-contact water level measurement in household appliances, medical equipment, industry and other fields.

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1.Introduction

The pneumatic liquid level sensor measures the water level based on the principle that the liquid generates a hydrostatic pressure at the bottom of the water tank which is proportional to the liquid height and density. NSPGD1 series pressure sensor uses a MEMS piezoresistive gauge pressure sensor element as a pressure sensitive component that provide an original signal output that is proportional to hydrostatic pressure. In household appliances, the NSPGD1 liquid level sensor can realize intelligent functions such as high and low liquid level reminder, water shortage reminder, water shortage and power failure protection, anti-overflow reminder, and can obtain the real-time water volume of the water tank. NSPGD1 supports analog output / digital output (I2C) and unique frequency output function, which is very convenient for application in various household appliances.

2.Hydrostatic pressure measurement

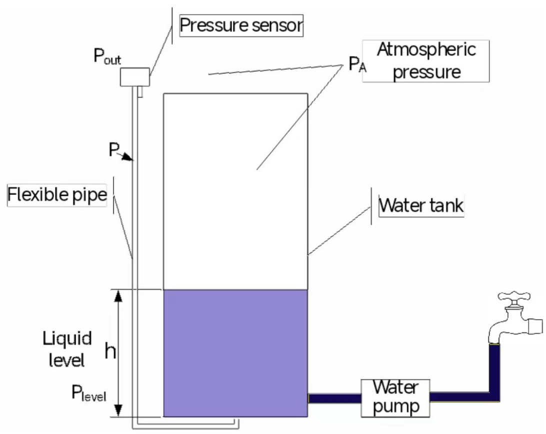


Figure 2.1 Hydrostatic pressure

The pressure in the flexible pipe has the following relationship with atmospheric pressure and sensor output pressure.

$$P_{out} = P - PA$$

At the same time, the pressure in the flexible pipe has the following relationship with the atmospheric pressure and the hydrostatic pressure generated by the liquid.

$$P = P_{level} + PA$$

Therefore, the sensor output pressure equal to the hydrostatic pressure.

$$P_{out} = P_{level}$$

According to the liquid pressure formula, the liquid height can be obtained from the output pressure of the sensor.

$$h = P_{out} / (\rho \times g)$$

Note:

P_{out} is the sensor output pressure ; P is the pressure in the flexible pipe;
P_A is the atmospheric pressure; P_{level} is the hydrostatic pressure generated by the liquid;
h is the liquid height; ρ is the water density;
g is Gravitational acceleration;

3.Transfer function

NSPGD1 pressure sensor supports a variety of output forms. To facilitate application, the transfer functions of different output types are introduced below.

3.1.Analog output

Taking the Ratiometric output mode as an example (the output voltage is the percentage of the power supply voltage), The part No. NSPGD1F002RT02 with the pressure range 0kPa ~ 2kPa, P_{max} is 2kPa output 90%VDD, P_{min} is 0kPa output 10%VDD, and the typical transfer function is:

$$VOUT = (A \times P + B) \times VDD$$

Note:
VOUT is the analog output, unit is V;
P is the pressure value, gauge pressure, unit is kPa/mmH2O;

Table 3.1 Analog Output Transfer Function Coefficient

Product NO.	Pressure range		Output range		Gain and offset	
	P_L	P_H	O_L	O_H	A	B
NSPGD1F002RT02	0kPa	2kPa	0.1*VDD	0.9*VDD	0.4	0.1

Table 3.2 Typical pressure and output voltage

P_{test}	VOUT	
	@VDD=3.3V	@VDD=5V
0kPa	0.330V	0.500V
0.5kPa	0.990V	1.500V
1kPa	1.650V	2.500V
1.5kPa	2.310V	3.500V
2kPa	2.970V	4.500V

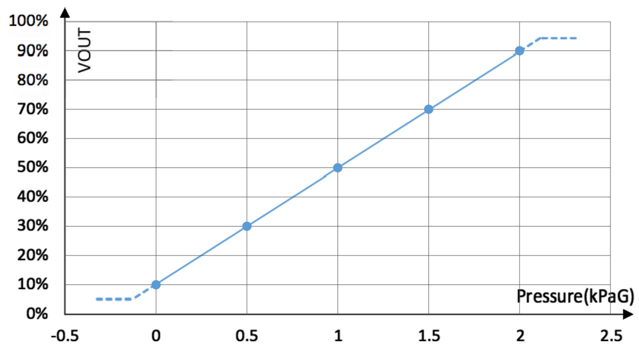


Figure 3.1 Typical analog output curve

3.2.Frequency output

Taking the part No. NSPGD1F004FT12 as an example. The frequency output transfer function is as follows.

$$FREQ = (A \times P + B) \times F.S.$$

Note:

1)FREQ is the frequency output, unit is kHz;

2)P is the pressure value, gauge pressure, unit is kPa/mmH2O;

3)F.S. is the full scale of frequency output. The chip can be configured with four full-scale frequencies, which are 250kHz, 125kHz, 61.5kHz, and 31.25kHz;

Table 3.3 Frequency Output Transfer Function Coefficient

Product NO.	Pressure range		Output range		Gain and offset		Full scale
	P_L	P_H	O_L	O_H	A	B	F.S.
NSPGD1F002RT02	0mmH2O	350mmH2O	3.125kHz	28.125kHz	0.002285714	0.1	31.25kHz

Table 3.4 Typical pressure and output frequency

P_{test}	Frequency
0 mmH2O	3.125kHz
50 mmH2O	6.696 kHz
100 mmH2O	10.268 kHz
150 mmH2O	13.839 kHz
200 mmH2O	17.411 kHz
250 mmH2O	20.982 kHz
300 mmH2O	24.554 kHz
350 mmH2O	28.125 kHz

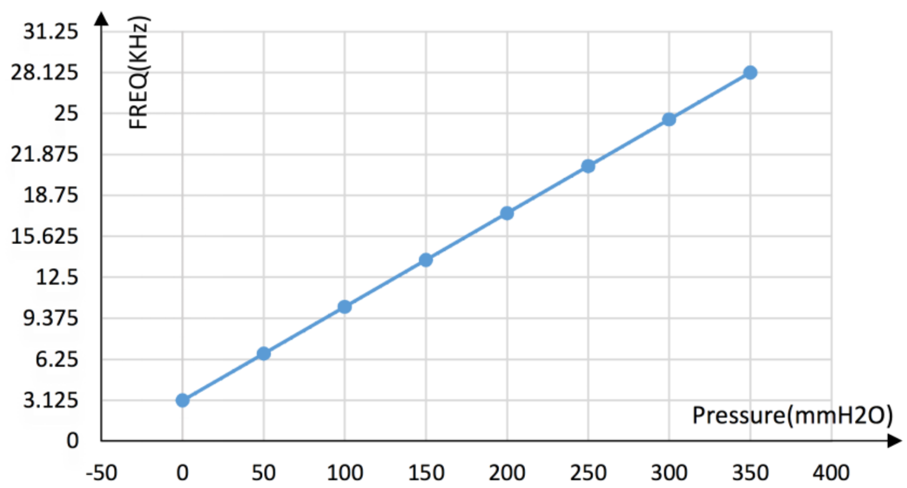


Figure 3.2 Typical frequency output curve

3.3.I²C output

Taking the part No. NSPGD1F006DT04 as an example. The I²C output transfer function is as follows.

$$Code= (A \times P + B) \times 8388607$$

Code is the register 0x06~0x08 value;

P is the pressure value, gauge pressure, unit is kPa/mmH2O;

Table 3.5 Digital Output Transfer Function Coefficient

Product NO.	Pressure range		Output range		Gain and offset	
	P_L	P_H	O_L	O_H	A	B
NSPGD1F006DT04	0kPa	6kPa	838861	7549746	0.13333	0.1

Register Map:

Addr	Bit Addr	Description	Default	Description
0x30	7 – 4	Reserve	4’b0000	Write with 0x0A to start a conversion, automatically come back to 0x02 after conversion ends.
	3	Sco	1’b0	
	2 – 0	Measurement_ctrl<2:0>	3’b000	
0x06	7 – 0	PDATA<23:16>	0x00	Output Pressure Data. Code = $Data0x06*2^{16}+ Data0x07*2^{8}+ Data0x08$;
0x07	7 – 0	PDATA<15:8>	0x00	
0x08	7 – 0	PDATA<7:0>	0x00	

For example:

If the value of the registers 0x06、0x07、0x08 are 0x3F, 0xFF, 0xFF, according to NSPGD1F006DT04 transfer function, Code = 4194304, P(kPa) = (4194304/8388607-B)/A, and finally get the value of pressure about 3kPa.

Table 3.6 Typical pressure and output code

P_{test}	Code
0 kPa	838861
1 kPa	1957342
2 kPa	3075823
3 kPa	4194304
4 kPa	5312784
5 kPa	6431265
6 kPa	7549746

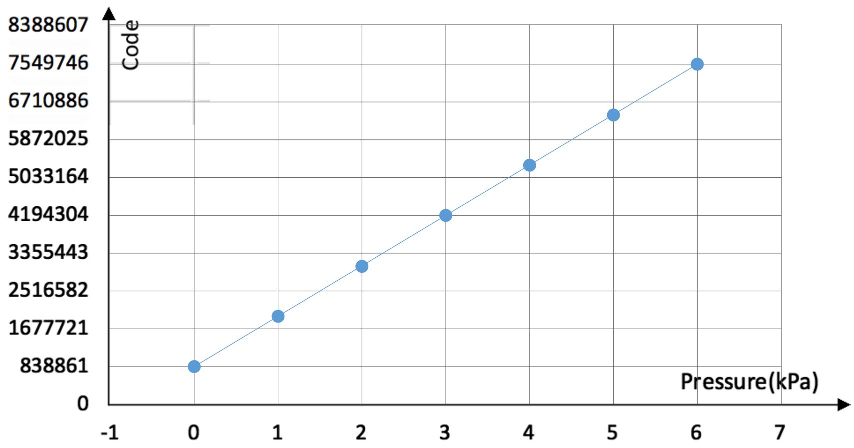


Figure 3.3 Typical I²C output curve

4. Application circuit

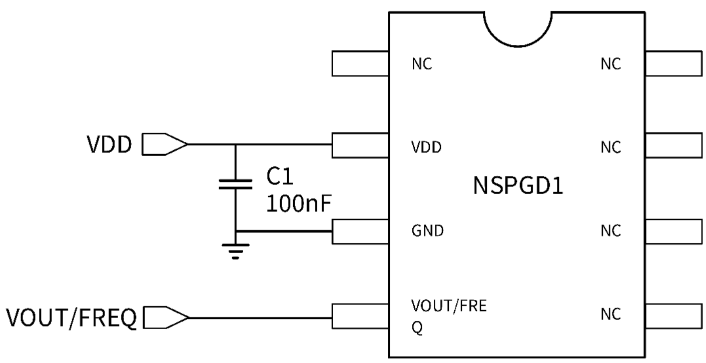


Figure 4.1 Analog/ Frequency Output Application Circuit

Note: For applications with higher ESD requirements, it is recommended that customers use the Figure 4.2 protection circuits.

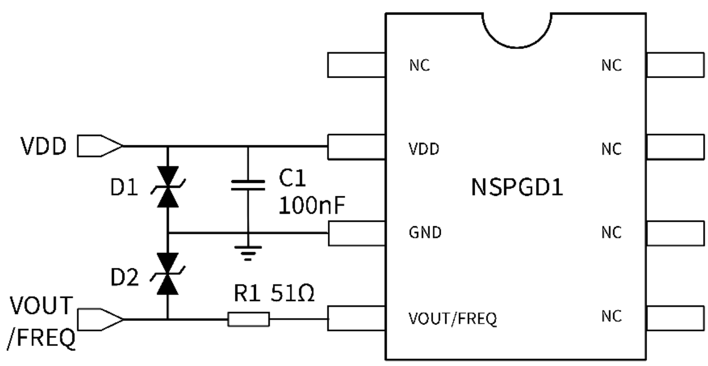


Figure 4.2 Analog/ Frequency Output Protection Circuit

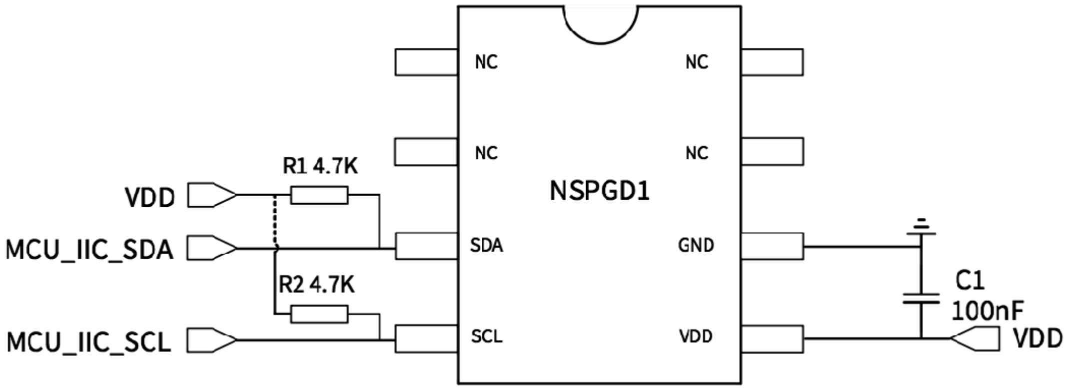


Figure 4.3 I²C Output Application Circuit

5.Water level sensor PCB layout

A good PCB layout can ensure product output stability and product performance. Figure 5.1 shows the PCB layout of water level sensor module applied in batch on the washing machine. This PCB adopts output protection circuit. Add peripheral ESD protection devices around NSPGD1 to reduce device damage caused by ESD problems such as static electricity and surge.

- Adding 100nF filter capacitor between VDD and GND can stabilize the input power supply and reduce the noise coupled to the power supply. The capacitor shall be located as close to the VDD pin as possible.
- Adding a resistance of 50 Ω between out and GND can prevent ASIC DAC damage caused by ESD introduced from out end.
- Add two TVS between VDD-GND and OUT-GND pins or add a SOT23 packaged dual TVS device. The common end is GND, and the other two ends are VDD and OUT.
- PCB should use a large area of ground copper.

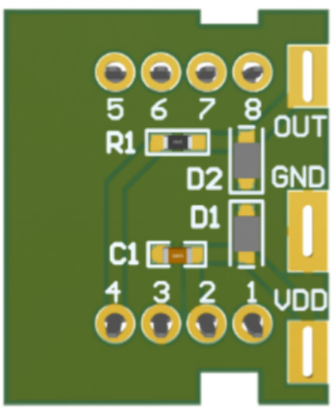


Figure 5.1 Water level sensor PCB layout

6.Reference application structure

The sensor is connected to the bottom of the water tank through the flexible pipe. The height of the water level in the water tank rising or falling will be proportional to the change of the liquid pressure. Through NSPGD1 high-precision sensor, the liquid height in the water tank can be obtained in real time. According to the control logic of different household appliances, it can automatically supply or transport water.

6.1.Portable tank

The portable water tanks or electrical appliances with compact space structure, such as coffee machines, water dispensers, soymilk machines, etc., can adopt the structure shown in the figure. The sensor flexible pipe is connected to the water outlet of the water tank base. The diameter of the water outlet connected to the base of the water tank shall be as large as possible to make the gas pressure conduct better.

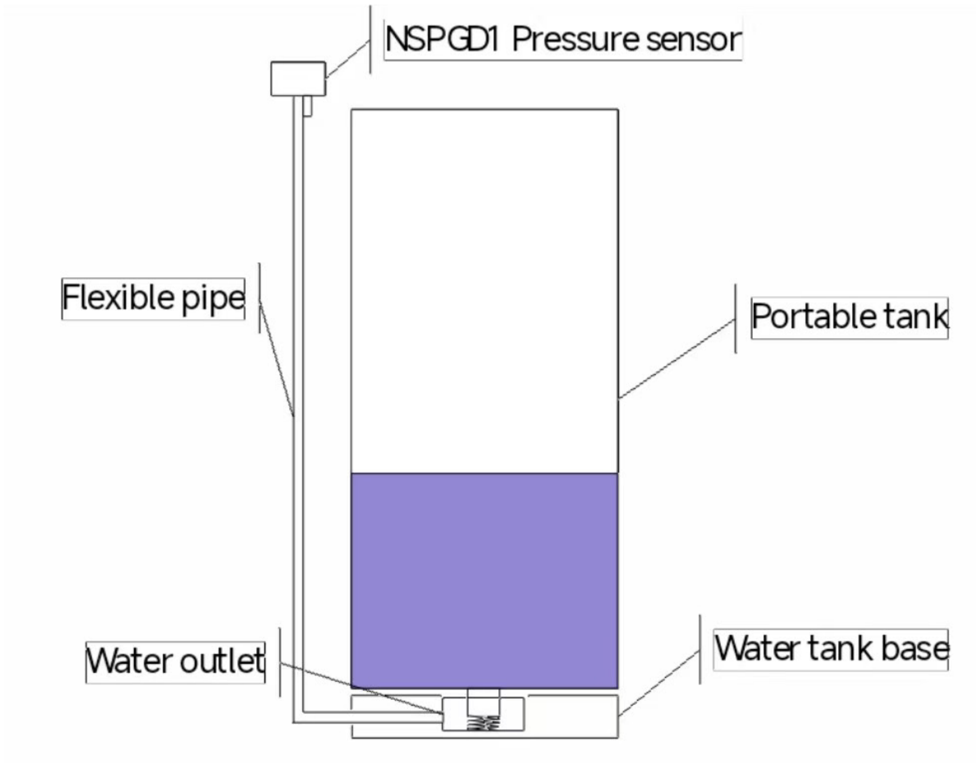


Figure 6.1 Portable tank structure

6.2.Fixed tank

For electrical appliances with large spatial structure, such as washing machines and dishwashers, fixed water tanks with air chambers can be used. This structure can ensure that the test zero point is relatively stable.

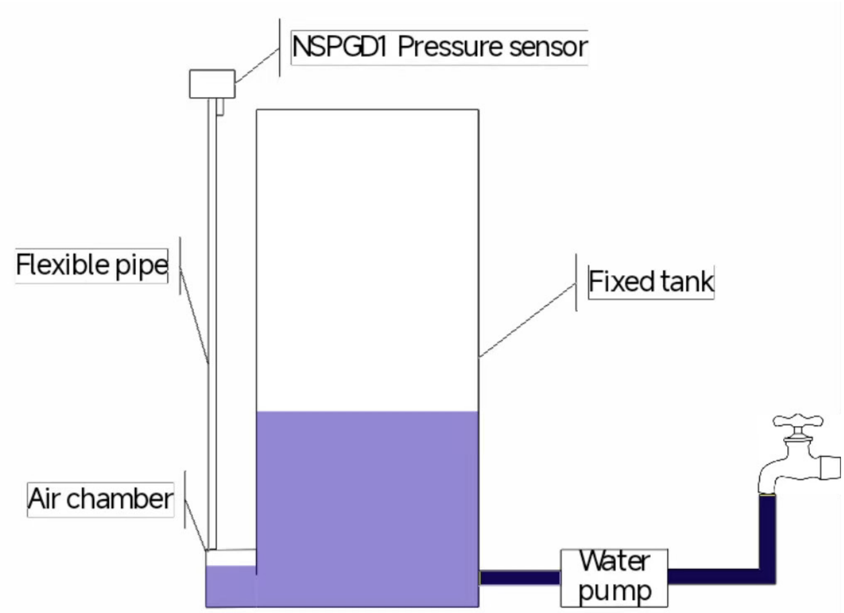


Figure 6.2 Air chamber integrated water tank structure

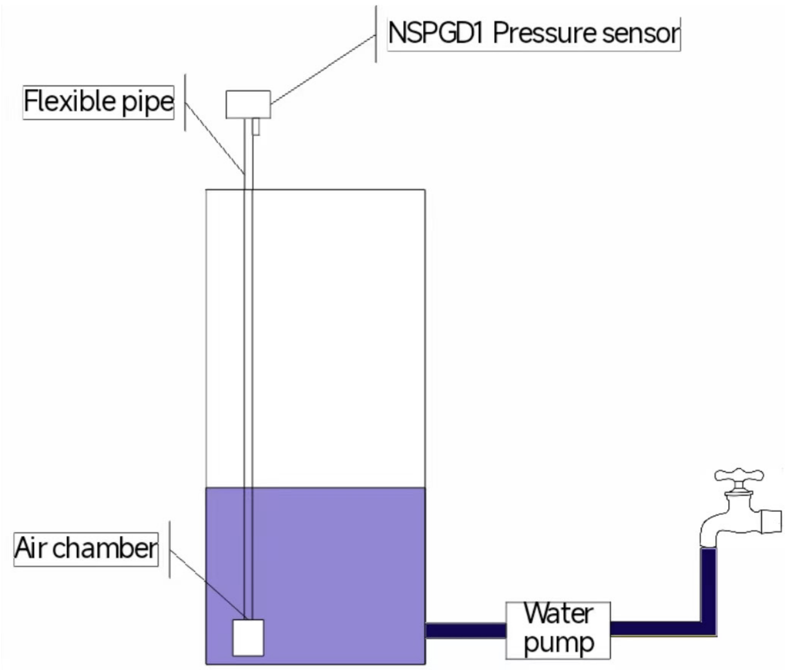


Figure 6.3 Independent air chamber water tank structure

6.3.Installation position

The installation position of the sensor shall be higher than the highest liquid level to be measured. Avoid damage caused by air leakage of the flexible pipe and water back pouring into the sensor.

7.Pressure sensor data processing

This part takes the output NSPGD1 of I2C as an example to introduce the data processing of liquid level and pressure sensors. In this example, the actual flexible pipe is installed at the bottom of the liquid tank. After impounding, some water will enter the flexible pipe and form part of the pressure, which may lead to the overall drift of the zero point. Therefore, it is necessary to add water for testing and compensate the zero pressure according to the actual situation. Due to the difference in the inner diameter and installation position of the flexible pipe, the specific offset value needs to be obtained through actual test. The calculation method of sensor measurement data and liquid level height is as follows:

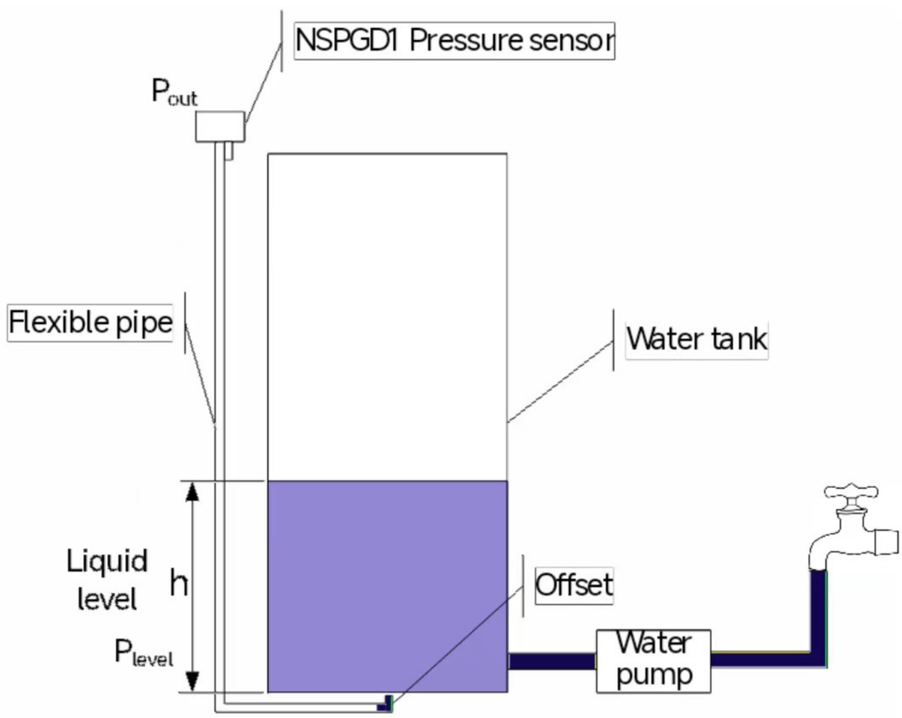


Figure 7.1 Application structure

7.1.Formula calculation

$$P_{level} = \rho \times g \times h$$

Assuming that the sensor output is 0~6kPa, the corresponding code value is 838861~7549746.

$$P_{out} = (Code/8388607 - B - offset) / A$$

Note:

P_{level} is the pressure generated by the liquid on the bottom of the liquid barrel;

ρ is the liquid density. Assuming that there is water in the liquid barrel, the density of water ρ is 1.0*10^3kg/m^3;

g is gravity acceleration 9.8m^2/s;

h is the liquid height;

P_{out} is the pressure output from the pressure sensor;

offset is the zero drift value caused by water entering the flexible pipe;

Then the liquid height h can be obtained from the following formula:

$$h = P_{level} / (\rho \times g) = P_{out} / (\rho \times g)$$

7.2.Calibration conversion

By calibrating the relationship between the liquid level height h of the container and the sensor code, the transfer function of h and code is obtained. The liquid level height can calculated by code.

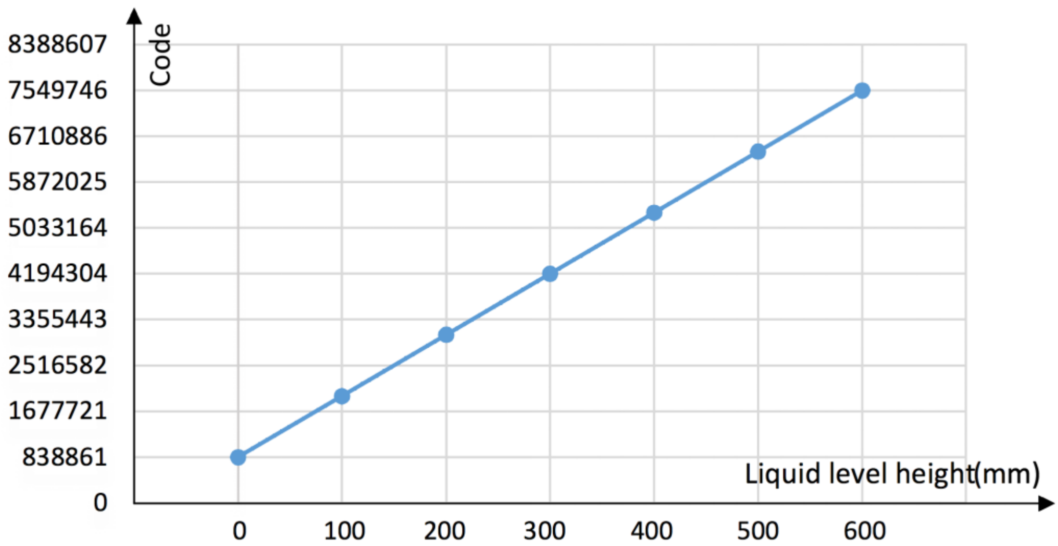


Figure 7.2 Calibration conversion

8.Comparison test between NSPGD1 and Hall rotor water flowmeter

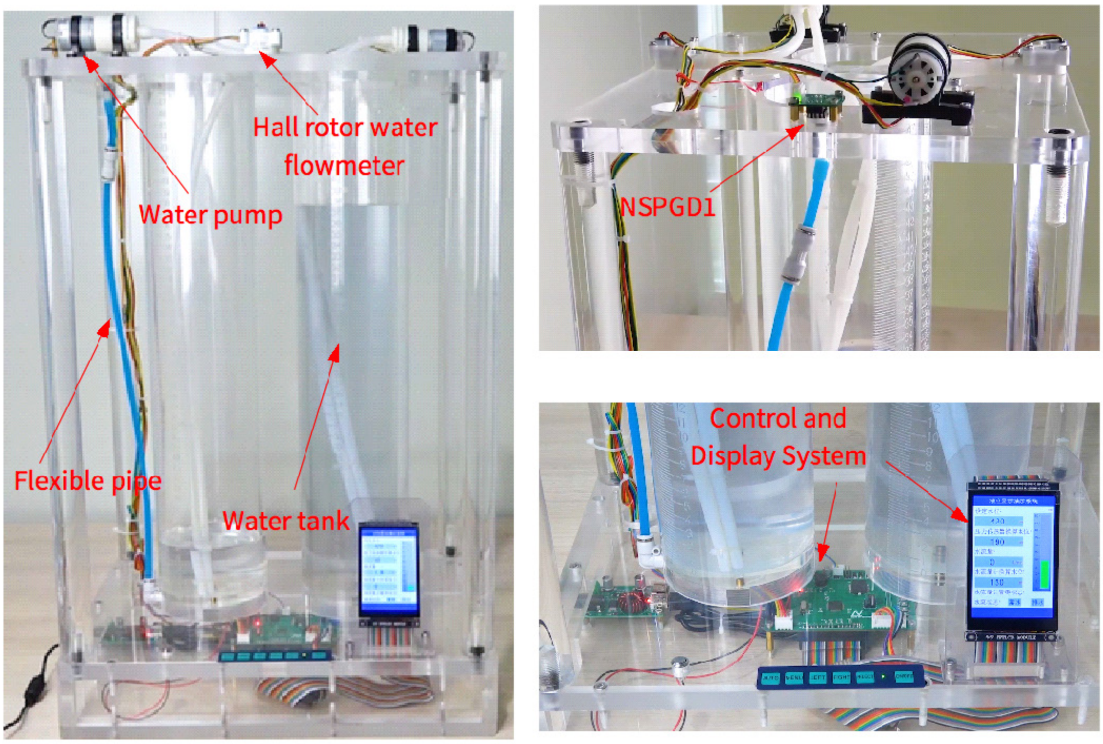
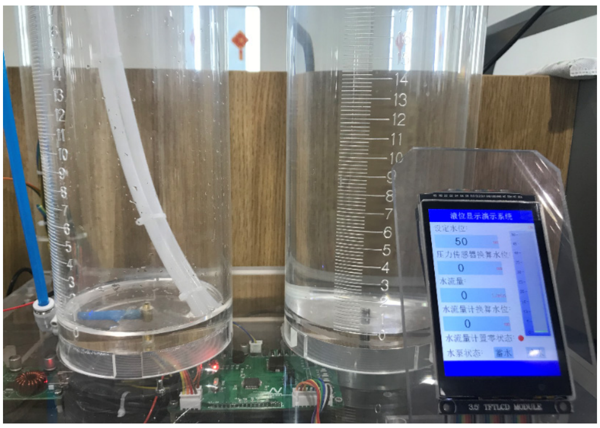
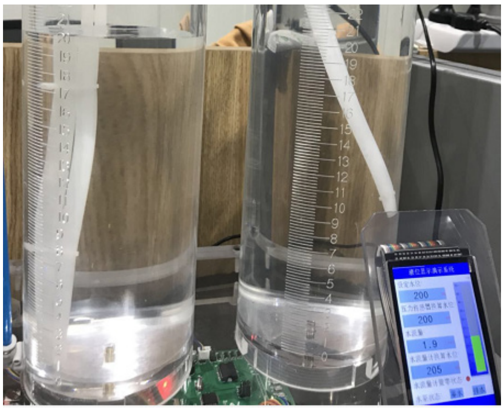
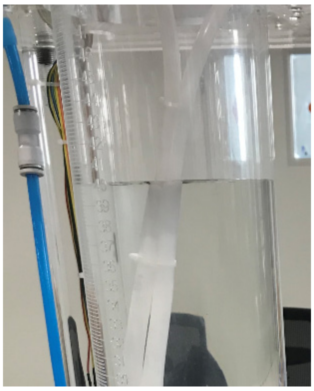
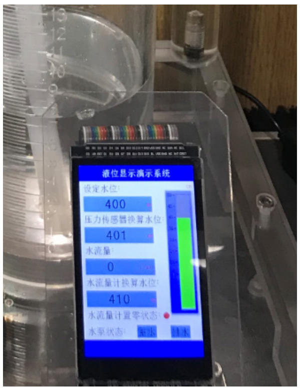
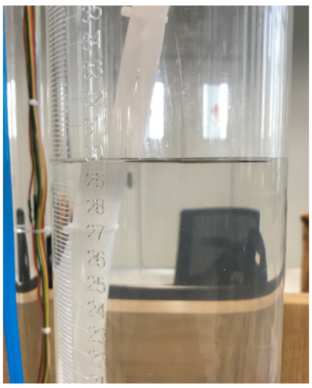
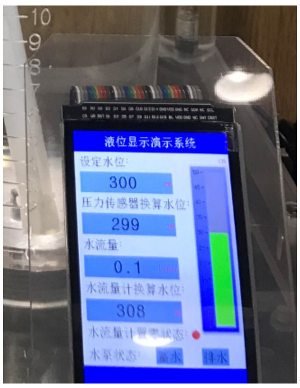


Figure 8.1 Liquid level test DEMO

Table 8.1 Comparison test between NSPGD1 and Hall rotor water flowmeter

1		Empty the water tank. Zero setting of water flowmeter. Set water level separately 50mm,200mm,400mm,300mm. And click Run.

2		The water surface rises to 51mm. The water level converted by NSPGD1 is 50mm. The water level converted by flowmeter is 52mm.
3		The water surface rises to 202mm. The water level converted by NSPGD1 is 200mm. The water level converted by flowmeter 205mm.
4	 	The water surface rises to 400mm. The water level converted by NSPGD1 is 401mm. The water level converted by flowmeter is 410mm.
5	 	The water surface rises to 298mm. The water level converted by NSPGD1 is 299mm. The water level converted by flowmeter is 308mm.

The following test results are obtained from four test points with water levels of 50mm, 200mm, 400mm and 300mm set in table 8.2:

Table 8.2 Test results

Set water level /mm	Actual water level /mm	NSPGD1			ODE AH97 Hall rotor water flowmeter		
		Water level /mm	Error		Water level /mm	Error	
			Absolute error /mm	F.S. Error %		Absolute error /mm	F.S. Error %
50	51	50	1	-0.16	52	1	0.16
200	202	200	2	-0.32	205	3	0.49
400	400	401	1	0.16	410	10	1.63
300	298	299	1	0.16	308	8	1.31

It can be seen from table 8.2 that the measurement result of NSPGD1 is more accurate than that calculated by hall rotor water flowmeter. Among the four test points, the maximum measurement error of NSPGD1 at 200mm is -0.32% (absolute error 2mm); Based on the real-time measurement of liquid pressure, NSPGD1 measurement error will not accumulate. The liquid level error data is relatively balanced and less than 2mm. After a long time of operation, the error of hall rotameter becomes larger due to the pulse cumulative error. The maximum measurement error is 1.63%, and the absolute error reaches 10mm.

9.Summary

NSPGD1 output value is linear with liquid level height value. It can be used for real-time liquid level detection without cumulative error, and can replace the rotor flowmeter to measure flow and volume. It can accurately measure the drop, leakage and water loss. Its unique frequency output function can directly replace the traditional mechanical liquid level sensor.

10.Revision history

Revision	Description	Author	Date
0.1	Initial version	Kun He	2020/05/20
1.0	English initial version, Update format and description.	Kun He	2022/06/24
1.1	Update Independent air chamber water tank structure.	Kun He	2023/08/18

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