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# Dew point measurement using a sensitive circuit type of dew point sensor

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**Abstract:** Aiming at the problem of atmospheric humidity measurement, this paper proposes a method to measure dew point based on sensitive circuit for the first time. We use the quartz crystal in the Colpitts circuit as the humidity sensitive element. Since the Colpitts circuit cannot drive quartz crystal oscillate in liquid environment, we use Peltier element to cool the quartz crystal until the dew is generated when the quartz crystal is in the liquid phase environment. The Colpitts circuit oscillation stops when the condensation occurs. At the same time it gets the temperature of quartz crystal surface when vibration stops so as to recognize and measure the dew point. Through the analysis of referenced data and experimental data, it is proved that the proposed method can be used for identifying the validity and accuracy of humidity from the qualitative point. The results are important and have practical significance for further quantitative analysis, research and development of sensitive circuit type dew point instrument.

**Keywords:** Colpitts circuit, dew point measurement, quartz crystal microbalance.

## 1 Introduction

The amount of moisture in the air is the so-called humidity. The precision, rapid measurement of humidity is one of the difficulties in chemical sensors. Usually it is expressed by such physical quantities as water vapor pressure, relative humidity, dew point temperature, mixing ratio, dry and wet bulb temperature difference and the saturation. The dew point temperature measurement has been internationally recognized as the most accurate method for measuring humidity.

The key technology of dew point measurement is the dew point detection and recognition. At present the main point identification technologies are photoelectric method, surface acoustic wave method, image recognition method and frequency method. The classical method of humidity measurement consists of doing an optical dew point detection, an original system has been developed in the laboratory making use of an optical emitter–detector and a Peltier module [1].The surface acoustic wave (SAW) technique has also been applied in dew point sensors. Here, the SAW sensor is cooled until condensation occurs on the surface. The formation of a thin water film gives rise to a sudden change of the delay time or resonance frequency. Vetelino et al. presented a SAW dew point sensor with a chilled Al mirror in between two IDE [2].The literature [3] study the new microscopic-imaging type dew point sensor, which uses optical capacitive coupling devices to detect differences between images from dew / frost generated by mirror. Literature [4,5] presents a QCM principle to identify dew point method.

This paper proposes the method to recognize the dew point based on the characteristics of Colpitts oscillation circuit for the first time, and design a set of new dew point measurement device. From the qualitative point of view, the experiment proved that the method and the device for dew point measurement have good sensitivity and accuracy.

## 2 Experimental details

The sensing device which is shown in Fig. 2.1, consists of a AT cut quartz crystal resonator of which resonant frequency is 6MHz and a Peltier element and a heat pipe radiator.

Tie one side of the AT cut quartz crystal which consists of two sides with the electrode to the cold paste of Peltier element, and then fix the Peltier ele-

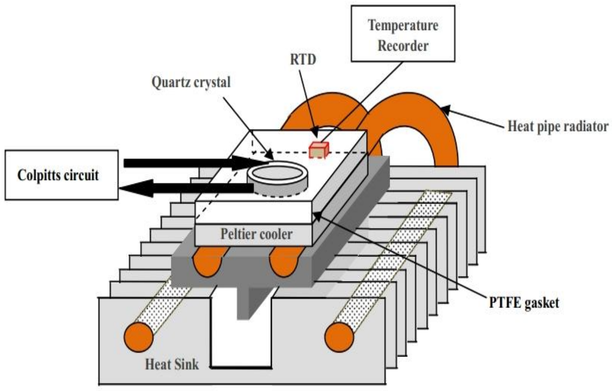


Figure 2.1. Schematic diagram of dew point sensor

ment with quartz by PTFE gasket groove, the heat surface of Peltier element should be attached to radiator so as to play a better cooling effect, lead out two wires respectively from the two electrodes in quartz crystal to get into Colpitts circuit. At the same time we need two platinum thermal resistance as temperature sensor, one is affixed to cold paste of refrigerator, acquire quartz crystal surface temperature according to the difference between quartz crystal and Peltier element, the other is exposed in the experimental environment to provide the ambient temperature at the same time.

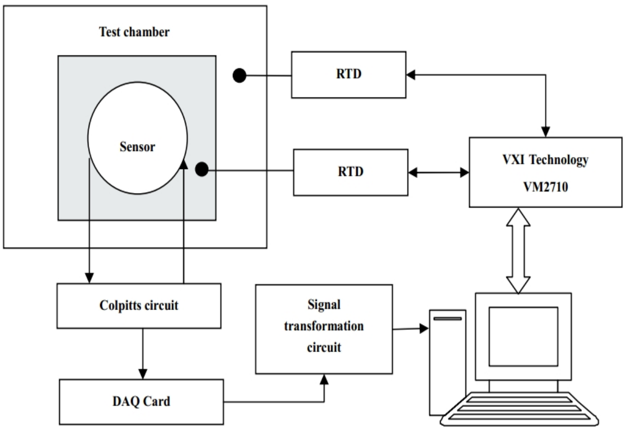


Figure 2.2. Experimental system of dew point measurement

Fig. 2.2 is diagram of experimental system, the acquisition card of system is PCI4712AS2 high speed data acquisition card, the Peltier element is the TEC1-3104 type, the maximum refrigerating power is 8.2W, the temperature sensor is PT100 platinum thermal resistance, digital multimeter is VM2710 based on VXI bus digital multimeter from VXI Technology company, which can converse value of the resistance of PT100 to temperature value, industrial control machine is the ADLINK industry control computer.

## 3 The Colpitts circuit analysis

The Colpitts circuit, which is often used in quartz crystal microbalance as a driving circuit, is a conventional oscillation circuit [6-7]. The quartz crystal as the sensitive element which is placed in Colpitts circuit can be only used to measure quality change in rigid adsorption. When the quartz crystal is placed in the liquid phase environment, its characteristics change in the circuit cause the circuit cannot meet the conditions to sustain oscillation and oscillation stops, and the response was very sensitive. This paper use the above characteristics of Colpitts circuit recognize dew point.[8]

Fig. 3.1 is the experiment circuit. The specific parameters are different according to the adjustment of crystal. The following is the analysis of the condition of resonance circuit.

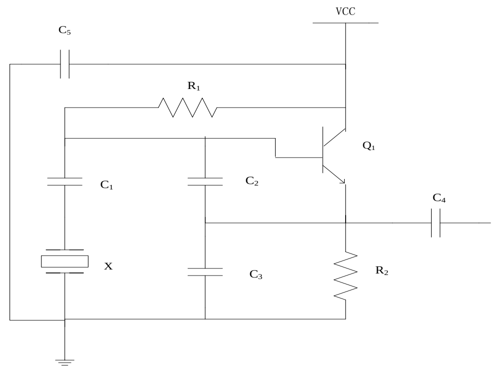


Figure 3.1. Colpitts circuit

Fig. 3.2 is equivalent circuit to Colpitts circuit. $U_{be} = U_i$ , $g_m = \frac{b}{R_i}$ , $b = \frac{b_0}{1 + j\frac{f}{f_b}}$ , $R_i$ is amplifier input resistance, $b_0$ is amplification of low frequency common emitter current, $f_b$ is the frequency of common emitter transistor cutoff, $X_1$ is the impedance crystal oscillator and series and parallel $R_1$ , $X_2$ is the impedance of $C_2$ , $X_3$ is the impedance of parallel between $C_3$ and $R_1$ .

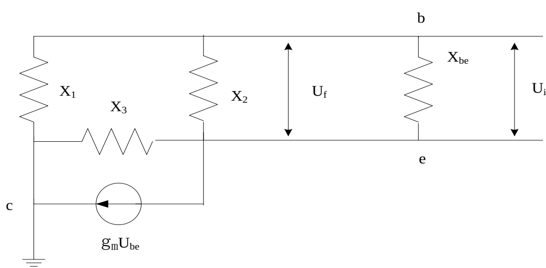


Figure 3.2. Equivalent circuit of Colpitts circuit

When the circuit is in the resonant state, should be in two condition:

$$|G| = 1;\ j = 2np\left(n = 0,1,2,\ldots\right) \quad (1)$$

The amplitude characteristic should meet the total loop gain of 1, frequency characteristics should meet the total loop phase and *n* multiply 360, (*n* =0, 1, 2, ...). When disconnect feedback, disconnect from three transistor b pole connection, see from the left of :

$$U_f = i_2 X_2 \quad (2)$$

From the current source above:

$$i_2 = -g_m U_i \frac{X_3}{X_1 + X_2 + X_3} \quad (3)$$

$$G = \frac{U_f}{U_i} = -g_m \frac{X_2 X_3}{X_1 + X_2 + X_3} = |G| e^{jj} \quad (4)$$

$G$ meets $|G| = 1, j = 2np\left(n = 0,1,2,\ldots\right)$, so,

$$X_1 + X_2 + X_3 + g_m X_2 X_3 = 0 \quad (5)$$

$$X_2 = \frac{1}{jwC_2},\ X_3 = \frac{R_2}{1 + jwR_2C_3},\ X_2X_3 = -\frac{R_2}{w^2R_2C_3 - jwC_2}$$

Take them into the Eq. (5) to get that:

$$X_2 + X_3 + g_m X_2 X_3 = \frac{\left(C_2 + C_3\right)w^2R_2^{\ 2}C_3 + C_2\left(g_m R_2 + 1\right)}{\left(w^2R_2C_3\right)^2 + \left(wC_2\right)^2} = R_N + jX_{CL} \quad (6)$$

$R_N$ is a negative gm resistance, is external circuit equivalent capacitance impedance.

In order to satisfy a resonance condition, should be equivalent to an electric resistance and series inductance impedance.

$$X_1 = \frac{XR_1 + \dfrac{R_1}{jwC_1}}{X + \dfrac{1}{jwC_1} + R_1} = \frac{R_1\left(1 + jwC_1X\right)}{1 + jwC_1\left(X + R_1\right)} \quad (7)$$

Among them, the impedance $X$ of crystal:

$$X = \frac{R_q + j\left[\left(L_q\omega - \dfrac{1}{C_q\omega}\right)\left(1 + \dfrac{C_0}{C_q} - C_0L_q\omega^2\right) - R_q^{\ 2}C_0\omega\right]}{\left(1 + \dfrac{C_0}{C_q} - C_0L_q\omega^2\right)^2 + \left(R_qC_0\omega\right)^2} \quad (8)$$

$$= R_X + jX_{IL}$$

Take Eq. (8) into Eq. (7)

$$X_1 = \frac{R_1\left(1 - wC_1X_{IL}\right)^2 + w^2C_1^{\ 2}R_X\left(R_X + R_1\right)}{\left(1 - wC_1X_{IL}\right)^2 + w^2C_1^{\ 2}\left(R_X + R_1\right)^2} - \frac{jwC_1R_1^{\ 2}\left(1 - wC_1X_{IL}\right)}{\left(1 - wC_1X_{IL}\right)^2 + w^2C_1^{\ 2}\left(R_X + R_1\right)^2} \quad (9)$$

Credited as: $X_1 = \mathrm{R_e} + jX_e$ (10)

Because $R_e + R_N = 0,\ X_e + X_{CL} = 0\ X_{CL} < 0,\ X_e > 0$ , so

$$X_{IL} > \frac{1}{wC_1} \quad (11)$$

Through the above analysis on the Colpitts circuit, conditions to maintain the oscillation of this circuit can be gotten. This circuit has the advantages of high frequency stability, but the drawback is the difficulty in the liquid phase working environment.

## 4 Electrical characteristics of quartz crystal

Quartz crystal equivalent circuit is shown in Fig. 4.1 Dynamic inductance $L_q$ is large, typically accounts to tens of millihenries to dozens of Henry; dynamic capacitance $C_q$ is very small, typically 10-3PF magnitude; dynamic resistance $R_q$ is very small, usually a few Ω to hundreds of Ω; the static capacitance $C_0$ is very small, generally about 2~5PF.

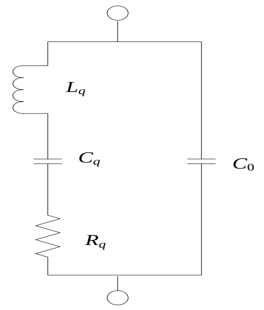


Figure 4.1. Equivalent circuit of quartz crystal

In order to analyze the reason oscillation circuit is difficult to work in the liquid; we firstly look at the real and imaginary parts of the curve of the quartz crystal admittance, as shown in Fig. 4.2 :

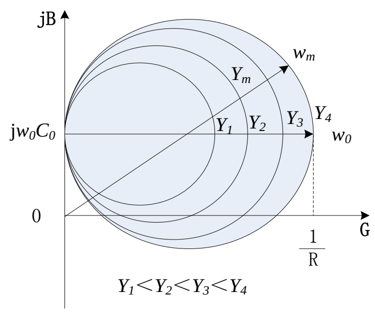


Figure 4.2 . Admittance of quartz crystal

As the crystal equivalent resistance $R_q$ increases, the radius of the circle continues decreases; on the same $R_q$, with the increasing of frequency w, crystal admittance move on the circle counterclockwise.

Crystal admittance $Y$ is following:

$$Y = \frac{R_q + j\left[R_q^2 C_0 \omega - \left(L_q\omega - \frac{1}{C_q\omega}\right)\left(1 + \frac{C_0}{C_q} - C_0 L_q \omega^2\right)\right]}{R_q^2 + \left(L_q\omega - \frac{1}{C_q\omega}\right)^2} \tag{12}$$

$$Y = Gx + jB = \frac{1}{X} = \frac{1}{R_X + jX_{IL}} \tag{13}$$

$$X_{IL} = -B\left(Gx^2 + B^2\right) \tag{14}$$

Take Eq. (14) into Eq. (11), if it meet the resonant condition, the crystal must be inductive. With the condensation increasing, $R_q$ gradually increases to a certain degree, so that Eq. (14) in the crystal perceptual frequency $w$ cannot meet the Eq. (11) conditions, and even crystals cannot be inductive, then the circuit will not satisfy a resonance condition and stop the vibration.

## 5 Signal conversion

According to the crystal itself as well as Colpitts circuit characteristic above, we can initially know when water condensation produced by Peltier cooling appears on the surface of quartz crystal, as crystal equivalent resistance is large in the liquid, the gain of amplifier is limited, amplitude characteristic is hard to meet, and the shunt capacitance introduced in the liquid is large, frequency characteristics of the oscillation circuit can be difficult to meet, so circuit stop oscillation, frequency output is zero.

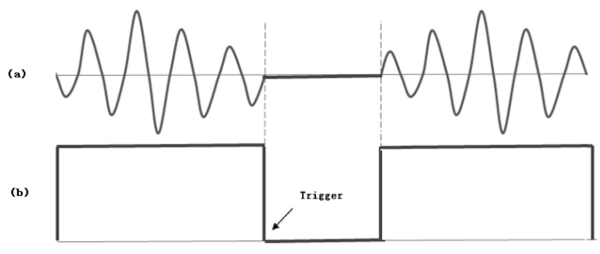


Figure 5.1. Schematic diagram of signal transformation

In order to capture the time when circuit oscillation stops accurately and triggers the temperature sensor when vibration moment stops, transform the original sinusoidal oscillation signal to a square wave signal which is easily measured with signal transformation circuit, trigger the temperature sensor when the intermittent square wave signal declines, acquire dew point and ambient temperature. Fig. 5.1 is signal transform schematic diagram, Fig. 5.1(a) is original signal and Fig. 5.1(b) is square wave signal.

## 6 Quartz crystal temperature determination

As platinum thermal resistance measured is the cold surface of Peltier element temperature, in order to obtain the quartz crystal surface temperature, we must take both temperature test and analysis. Fig. 6.1 is temperature relationship between quartz crystal surface and the cold surface of Peltier element in the stability of the refrigeration power and experimental ambient temperature.

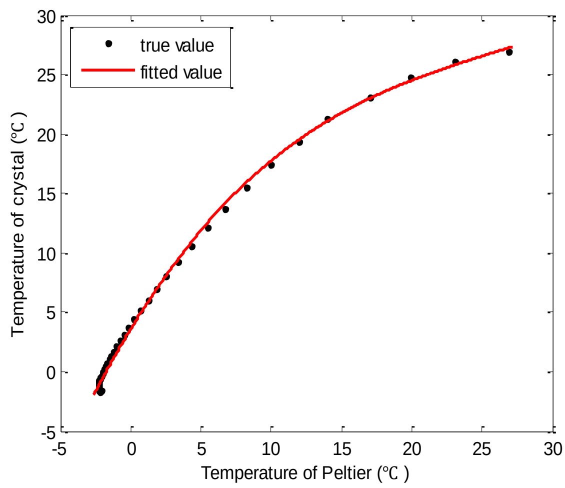


Figure 6.1. Temperature curve

Through fitting the actual data, we can get the temperature curve between quartz crystal surface and the cold surface of Peltier element, as is shown in Fig. 6.1 , and we can get the fitting cubic-curve equation:

$$T_{crystal} = 0.0007591 T_{Peltier}^3 - 0.05966 T_{Peltier}^2 + 1.935 T_{Peltier} + 3.587$$

Using this equation the quartz crystal surface temperature can be obtained according to the temperature of cold surface of Peltier element.

## 7 The dew point measurement

As the measurement process is shown in Fig. 7.1, we select seven groups of different relative humidity to verify the measurement device. Experiment takes 2.5A as a Peltier element operating current, environment temperature is 26.88℃. Environment humidity data is provided by HM1500 capacitive humidity sensor, accuracy is ±3%.

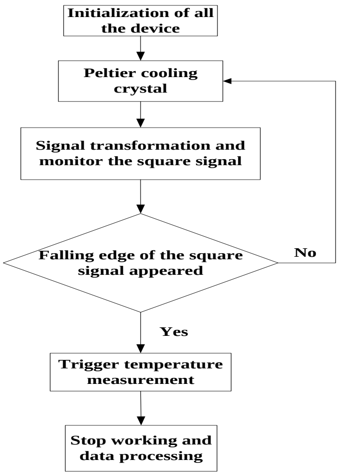


Figure 7.1. Experimental procedure

Fig. 7.2 is time required in the seven different groups of humidity environment using the designed device measured the quartz crystal surface temperature and the time needed to stop circuit oscillation, the solid line shows the quartz crystal surface temperature, the dotted line is the time needed to stop circuit oscillation. Seven groups of environmental humidity provided is increasing in turn, we can see from the diagram that as humidity increases, leading to the quartz crystal surface condensate thus enabling the circuit to stop vibration temperature turning larger in turn, at the same time the time circuit stops oscillating in turn is shorter, these two groups of data trends can be qualitative verification that the device is effective to the humidity sensitivity.

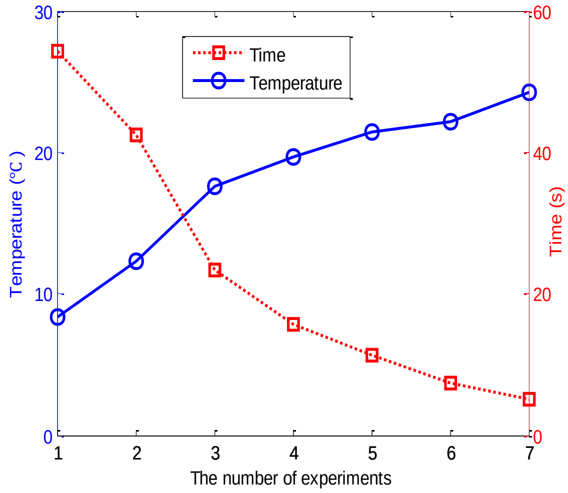


Figure 7.2. Measurement result

Table.7.1 lists all the contrast values of the measured data and the reference data. The error between measuring the dew point temperature and reference of the dew point temperature is in ±2.5 ℃ , error between calculating the relative humidity values and reference relative humidity is in ±5%. Through the comparative analysis of experimental data we can qualitatively validate that the device of humidity measurement has certain accuracy.

Table 7.1. Experimental data

| Number | Temperature (℃) | | | Relative humidity (%) | | |
|---|---|---|---|---|---|---|
| | $T_{crystal}$ | $T_d$ | Error | $RH_{referrnce}$ | $RH_{measured}$ | Error |
| 1 | 8.34 | 10.54 | 2.2 | 35.93 | 31 | 4.93 |
| 2 | 12.35 | 14.13 | 1.78 | 45.52 | 40.52 | 5.0 |
| 3 | 17.57 | 18.7 | 1.13 | 60.89 | 56.72 | 4.17 |
| 4 | 19.64 | 20.03 | 0.39 | 66.13 | 64.56 | 1.57 |
| 5 | 21.43 | 22.54 | 1.11 | 77.18 | 72.1 | 5.08 |
| 6 | 22.14 | 23.12 | 0.98 | 79.92 | 75.31 | 4.61 |
| 7 | 24.28 | 23.95 | -0.33 | 84.0 | 85.7 | -1.7 |

## 5. Conclusion

Based on the analysis of crystal itself as well as the Colpitts circuit, according to the oscillation starting condition and equilibrium condition of Colpitts circuit, the measuring method and a dew point sensor proposed in this paper for measuring humidity measurement is of feasibility. This device is of sensitivity and accuracy in humidity measurement from the perspective of qualitative on the comparative analysis between measuring data and the reference data. Because the characteristic of the circuit is related to the degree of condensation of the quartz crystal surface, it excludes impact of the temperature and atmospheric pressure in conventional methods of humidity measurement on the measuring result. The quartz crystal surface condensation degree is fixed when the circuit stops oscillation, this method is of stability. Validation results provide an important theoretical basis for further quantitative analysis and have important significance for developing the new resonant type dew point instrument.

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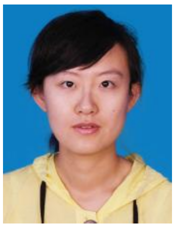

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