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Remote Measurement of the Dew Point by the Aquanal Hygrometer

Vladimir Lapčević[1)]
Aleksandar Vitić[1)]

This paper presents a device for the remote measurement of the dew point by the Aquanal hygrometer in the T-38 wind tunnel. The device for the remote measurement of the dew point is developed in the Military Tecnical Institute. The T-38 wind tunnel uses dry air with overpressure from 2600 cubic meter air storage tanks. The idea of the project was to enable remote measurement of the dew point. After a modification of the Aquanel hygrometer, an operator of the compressor will have information about the dew point of air on the monitor in front of him. The Aquanal hygrometer is placed at the output of the air tank in the T-38 wind tunnel

Key words: **wind tunnel, remote measurement, dew point.**

Introduction

THE dew point is the temperature at which the water vapor in a volume of humid air at a constant barometric pressure condenses into liquid water. The dew point is a very important parameter during the test run of the wind tunnel, especially for tests at high Mach numbers [1]. Air storage tanks are filled up with a five-stage compressor of 3.6 MW. The capacity of this compressor is 7.5 kilograms of air per second at 20 bars. There is an air drying system in the compressor station completed with two dryer assemblies and connecting piping, valves and fittings, as well. Each air drying system is filled with about 2 tones alumina oxide and silicate. These substances very efficiency remove humidity from the air. The dew point of the air on the exit of the air drying system in the T-38 wind tunnel is from -55°C up to -30°C [2]. The dryer efficiency depends on the mass flow of the air and the relative humidity of the atmospheric air. In the T-38 wind tunnel, the automatic system for dryer changing does not work. Instead by an automatic system, it is done by an operator of the compressor. The air must be dry enough for accurate measurements in the blowdown wind tunnel [3]. For that purpose, the Aquanal hygrometer [4] with the additional equipment is used for remote measurement. The Aquanal hygrometer enables only local measurement of the dew point. This device for remote measurement from the Aquanal sensor is realised in the Military Tecnical Institute. Remote measurement of the dew point is done by a 90-meter long cable which transmits current signals in a range from 0 mA to 20 mA. The information about a dew point value is comprised in that current. The Aquanal indicator shows only humidity in part per million (ppm) units on its display. The remote indicator calculates the dew point as a function of humidity and the humidity and the dew point are shown on the display. The schematic block diagram of a dew point measurement system is shown in Fig.1.

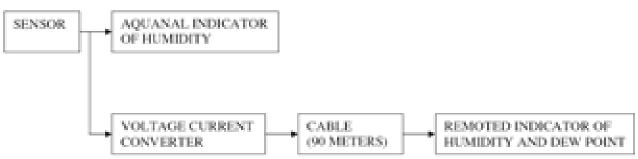

Figure 1. The schematic block diagram of a dew point measurement system

Desciption of the Aquanal hygrometer

The Aquanal hygrometer consists of a sensor, an indicator, a valve and an airflow meter which are all contained in a metal box. In Fig.2a) the front side of the Aquanal hygrometer is shown. The Aquanal hygrometer is located in the hall of T-38 wind tunnel [5-6] near the air storage tanks.

Figure 2. a) Front side of Aquanal hygrometer, b) Aquanal sensor

The Aquanal sensor (measurement cell) is realized by a glass stick which is very good insulator around which two platinum wires are wrapped at a very short distance. The Aquanal sensor is shown in Fig.2b). The glass insulator and wires are coated with a thin layer of phosphoric acid. To avoid a contact between the wires, grooves are milled into the insulation in which the wires are located. The water vapor contained in the air is absorbed by the layer of phosphoric acid and electrolytically decomposed by direct current flowing through the wires. The electricity which flows is proportional to the amount of water taken in.

1) Military Technical Institute (VTI), Ratka Resanovića 1, 11132 Belgrade, SERBIA

Measurement with the Aquanal sensor is possible only under low overpressure. The air arrives to the hygrometer by a pneumatic connector. The air passes through the regulation pressure valve which decreases pressure to low overpressure. The air from the output of the regulation valve comes to the airflow meter which has an additional function for mass flow regulation. The air to be measured flows through the measurement cell with a particular quantity of flow of 100 normal liters per hour. The air then comes to the box which contains the measurement cell. The Aquanal indicator measures the voltage from the measurement cell. This voltage is in a range from 0 mV to 200 mV, depending on air humidity.

The Aquanal indicator works in two ranges: 0.1 ppm - 199.9 ppm and 1 ppm – 1999 ppm. In a range from 0.1 ppm to 199.9 ppm, the voltage of 1 mV responds to the humidity of 1 ppm. In a range from 1 ppm to 1999 ppm, the voltage of 1 mV responds to the humidity of 10 ppm. The dew point value can be calculated by the humidity value and by Table 1 or the chart which is shown in Fig.3.

Table 1. Table for calculating the dew point by humidity

Humidity [ppm]	Dew point [°C]	Humidity [ppm]	Dew point [°C]
0.0923	-90	39.4	-50
0.134	-88	49.7	-48
0.184	-86	63.2	-46
0.263	-84	80	-44
0.382	-82	101	-42
0.526	-80	127	-40
0.747	-78	159	-38
1.01	-76	198	-36
1.38	-74	249	-34
1.88	-72	309	-32
2.55	-70	376	-30
3.44	-68	462	-28
4.6	-66	566	-26
6.1	-64	691	-24
8.07	-62	841	-22
10.06	-60	1020	-20
14	-58	1200	-18
18.3	-56	1490	-16
23.4	-54	1790	-14
31.1	-52	2140	-12

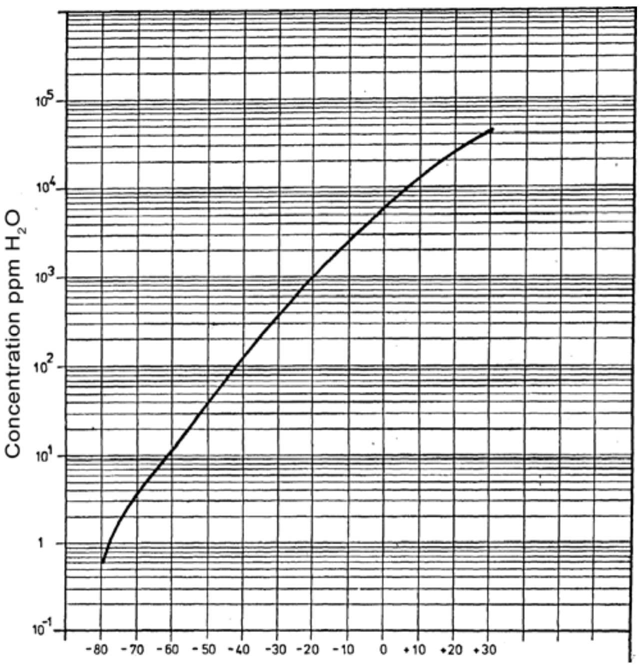

Figure 3. Dew point dependence on humidity, a logarithm chart

Description of the equipment for remote measurement

It is better to transmit DC current to a long distance than DC voltage because losses during transmitting are smaller. The Aquanal hygrometer does not have output current for remote measurement, so it was necessary to develop a voltage current converter for remote measurement. The voltage from the output of the sensor must be amplified first and then it can be converted to current. A device for amplifying sensor output voltage and converting voltage to current is developed in the Military Technical Institute and it is shown in Fig.4. It is mounted on the Aquanal hygrometer chassis. This device amplifies sensor output voltage in a range from 0 V to 200 mV and converts it into the output current in a range from 0 mA to 20 mA.

Figure 4. A voltage current converter mounted on the Aquanal hygrometer chassis

A remote indicator is mounted in the compressor station. It is connected by a cable, about 90 meters long, with a voltage current converter located in the wind tunnel hall. The Aquanal indicator measures a dew point temperature in a range from -69°C to -12°C.

The device for gaining sensor output voltage and conversion to current consists of an amplifier and a voltage current converter. The electrical configuration of this device is shown in Fig.5.

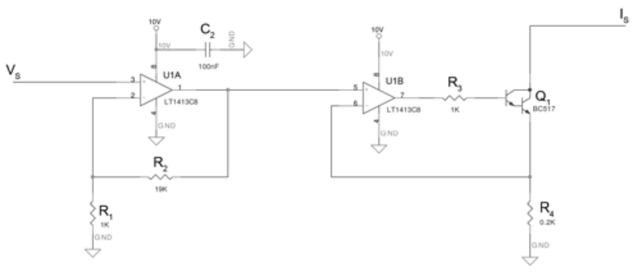

Figure 5. Electrical configuration of the voltage current converter

In Fig.5, the amplifier U1A and the resistors $R_1 = 1\ k\Omega$ and $R_2 = 19\ k\Omega$ present the voltage amplifier. This voltage amplifier amplifies sensor output voltage for $A = 20$ times:

$$A = 1 + \frac{R_2}{R_1} \tag{1}$$

In Fig.5, the amplifier U1B, the transistor Q_1 and the resistors R_3 and R_4 present the current voltage converter. The amplifiers U1A and U1B shown in Fig.5 are LT1413CN8 amplifiers [7]. The amplifier LT1413CN8 is chosen because it has a very low offset. The current I_{R4} which flows through the resistor R_4 is equal to the current I_E of the emitter of the transistor Q_1 :

$$I_{R4} = I_E = \frac{20 \cdot V_S}{R_4} \tag{2}$$

where:

V_S - sensor output voltage

$R_4 = 200\ \Omega$ - resistance of the resistor R_4

The maximum voltage $U_{R4\max}$ on the resistor R_4 is achieved when the sensor output voltage V_S has a maximum value $V_{S\max} = 200\ mV$:

$$U_{R4\max} = 20 \cdot V_{S\max} = 20 \cdot 200\ mV = 4\ V \tag{3}$$

In that case, the current I_{R4} which flows through the resistor R_4 has a maximum value $I_{R4\max}$:

$$I_{R4\max} = \frac{20 \cdot V_{S\max}}{R_4} = 20\ mA \tag{4}$$

The relation between the current of the collector I_C and the current of the emitter I_E of the transistor Q_1 is:

$$I_C = \frac{\beta}{1+\beta} \cdot I_E \tag{5}$$

The transistor used is the Darlington transistor BC517 and its current amplification has a very high level of $\beta = 30000$. Because of that, the current of the collector I_C and the current of the emitter I_E of the transistor Q_1 are approximately equal:

$$I_C \approx I_E \tag{6}$$

The current of the collector I_C of the transistor Q_1 is the output current of the voltage current converter I_S :

$$I_C = I_S = \frac{20 \cdot V_S}{R_4} \tag{7}$$

The remote indicator for measuring the dew point from the Aquanal hygrometer is developed in the Military Technical Institute and is shown in Fig.6, where H is humidity and D is the dew point. The interface circuit of the remote indicator is shown in Fig.7.

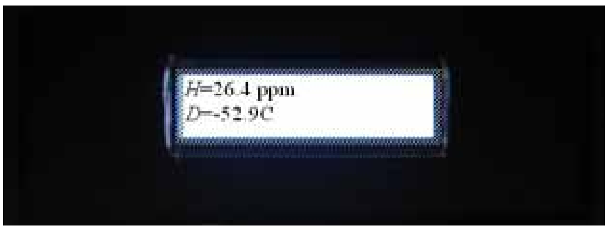

Figure 6. Remote indicator for measuring the dew point from the Aquanal hygrometer

At the input of the indicator, there is the resistor $R_7 = 200\ \Omega$ the value of which is equal to the value of the resistor R_4 in the voltage current converter. The output current I_S of the voltage current converter passes through the resistor R_7 and creates the voltage U_{R7} on it:

$$U_{R7} = R_7 \cdot I_S \tag{8}$$

By measuring voltage potentials at the ends of the resistor R_7, it is possible to calculate the transmitted current I_S . When the transmitted current I_S is known, then the sensor output voltage V_S is known as well. The measured electronics do not have influence on the measured voltage potentials. Two amplifiers have the gain equal to one and they are used as separation amplifiers. In order to have the measured voltage adjusted to the analog digital converter, a voltage divider is used. The voltage divider divides input voltage 3 times, because the maximum allowed voltage on the input of the analog digital converter is 5 V. The analog digital converter is integrated in the microcontroller ATMEGA 8 [8]. It is a 10-bit A/D converter with successive approximation. The resistors R_6 and R_8 contain one voltage divider and the resistors R_9 and R_{10} contain the other one voltage divider.

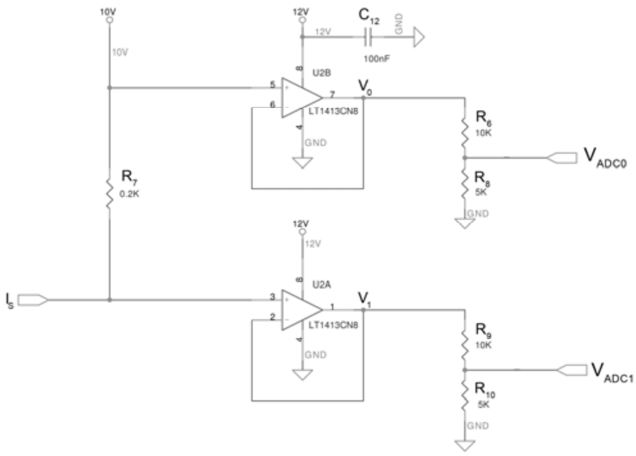

Figure 7. Interface circuit of the remote indicator

The A/D converter integrated in the microcontroller ATMEGA 8 has six channels (from 0 to 5). One voltage potential V_{ADC0} is measured on the one channel of the A/D converter (channel 0), and the other voltage potential V_{ADC1} is measured on the other channel of the A/D converter (channel 1).

$$V_{ADC0} = \frac{R_8}{R_6 + R_8} V_0 = \frac{1}{3} V_0 \tag{9}$$

where:

V_0 - voltage from the output of the amplifier U2B

$R_6 = 10\ k\Omega$ - resistance of the resistor R_6

$R_8 = 5\ k\Omega$ - resistance of the resistor R_8

$$V_{ADC1} = \frac{R_{10}}{R_9 + R_{10}} V_1 = \frac{1}{3} V_1 \tag{10}$$

where:

V_1 - voltage from the output of the amplifier U2A

$R_9 = 10\ k\Omega$ - resistance of the resistor R_9

$R_{10} = 5\ k\Omega$ - resistance of the resistor R_{10}

The referent voltage of the A/D converter is $V_R = 5V$. The result of the analog digital conversion of the voltage V_{ADC0} on channel 0 is a digital value d_0 .

$$d_0 = \frac{\left(2^n - 1\right) \cdot V_{ADC0}}{V_R} \quad (11)$$

where:
n - number of bits of the A/D converter.

The A/D converter has 10 bits and the digital value d_0 can be expressed:

$$d_0 = \frac{1023 \cdot V_{ADC0}}{V_R} \quad (12)$$

The result of the analog digital conversion of the voltage V_{ADC1} on channel 1 is a digital value d_1 :

$$d_1 = \frac{1023 \cdot V_{ADC1}}{V_R} \quad (13)$$

The transmitted current I_S is equal:

$$I_S = \frac{V_0 - V_1}{R_7} = \frac{3\left(V_{ADC0} - V_{ADC1}\right)}{R_7} \quad (14)$$

As the resistor R_4 in the voltage current converter has the same value as the resistor R_7 in the interface circuit of the remote indicator and because of equations (7) and (14), the next equation is appropriate:

$$V_S = \frac{3\left(V_{ADC0} - V_{ADC1}\right)}{20} \quad (15)$$

Using equations (12) and (13), equation (15) can be written as:

$$V_S = \frac{3\left(d_0 - d_1\right) \cdot V_R}{20 \cdot 1023} \quad (16)$$

By replacing V_R with 5 V in the last equation, the following equation can be obtained:

$$V_S = \frac{250\left(d_0 - d_1\right)}{341}\left[mV\right] \quad (17)$$

The minimum resolution of the measurement ΔV_S is obtained when the difference between the digital value of the measurement is equal to one:

$$d_0 - d_1 = 1 \quad (18)$$

The minimum resolution of the measurement is:

$$\Delta V_S = \frac{250}{341}\left[mV\right] = 0.73\ mV \quad (19)$$

For its work, the remote indicator demands 3 different power supplies: 5 V, 10 V and 12 V. The microcontroller ATMEGA 8 and the LCD display work on 5 V. The interface circuit for signal processing demands power supplies of 10 V and 12 V. The power supplies of 5 V, 10 V and 12 V are realized by linear regulators LM7805, LM7810 and LM7812, respectively.

The microcontroller ATMEGA 8 is a central part of the remote indicator. It has the integrated 10-bit A/D converter with successive approximation which enables a conversion of analog signals into digital signals. The microcontroller calculates a dew point value through the measured humidity and the polynomial of the second order and sends both values onto the LCD display. It controls the operation of the LCD display. The pin "PB0" of the microcontroller is configured as a digital input. This pin is intended for selecting a measurement range. The range of measurement must be the same at the Aquanal indicator and the remote indicator. When the switch on the remote indicator is turned on, the pin "PB0" of the microcontroller is connected to the ground and the microcontroller reads logical 0 on the pin "PB0". When the switch on the remote indicator is turned off, the pin "PB0" of microcontroller is at voltage of 5 V by a pull up resistor and the microcontroller reads logical 1 on the pin "PB0". When the microcontroller reads logical 0 on the input of the pin "PB0", then a low range is selected. When the microcontroller reads logical 1 on the input of the pin "PB0", then a high range is selected. When the switch is set, then the user must reset the remote indicator by pressing the reset taster. After resetting the state, the microcontroller reads a digital input on the pin "PB0" and a new mode of operation is set. The LCD display with 2 rows and 16 characters in each row is used. In a first row, the value of humidity is shown, and in the second row, a value of the dew point is shown. Fig.8 shows the dew point dependence on humidity. The Y-axis presents the dew point and the x-axis presents humidity in ppm units. This chart is based on Table 1, created in the Microsoft Excel program.

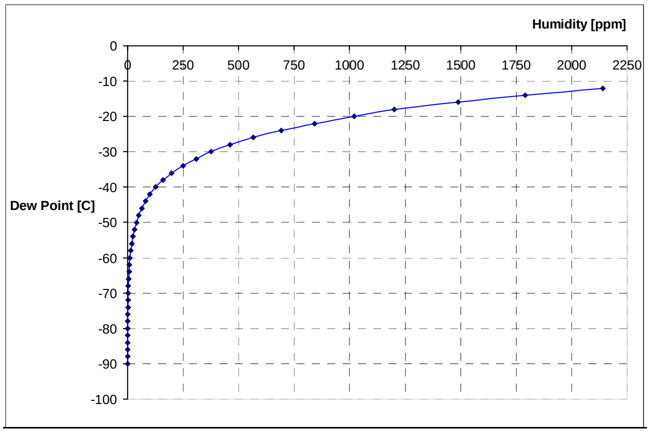

Figure 8. Dew point dependence on humidity in the linear scale

It can be seen from Fig.8 that the dew point dependence on humidity is extremely non linear. This characteristic can be divided into a few small characteristics, where every small characteristic presents the dew point dependence on humidity for slight changes of the dew point for 10 degrees. For slight changes of the dew point of 10 degrees, the dew point dependence on humidity can be presented with a square function. Figures 9-14 show the dew point dependence on humidity for a change of the dew point for 10 degrees. The characteristic obtained by a curve passing through the points from Table 1 is shown with a blue line. The interpolation curve of the second order can be created by these points from Table 1 and it is shown by a red line. Every polynomial interpolation for specified interval of dew point is shown by the its characteristics (Figures 9-14). This interpolation polynomial and the charts are obtained in the Microsoft Excel program. From Figures 9-14 it can be seen that the interpolation curve of the second order matches the curve which passes through all points for all figures. When the sensor output voltage is measured, then humidity is known. In the microcontroller program, the dew point is calculated using humidity and the polynomial of the second order. The dependence on the value of humidity will be an applied polynomial of the second order which is valid in that range of humidity. All polynomials of the second order used for calculating the dew point are given in Table 2.

Table 2. Dew point dependence on humidity in different ranges

Dew point y is a function of the humidity x	x[ppm] (humidity)	y [°C] (dew point)
$y=-2\cdot10^{-6}\cdot x^2+0.0136\cdot x-31.56$	$x\in[1020\,\text{ppm},\,2000\,\text{ppm}]$	$y\in[-20^\circ C,-12^\circ C]$
$y=-10^{-5}\cdot x^2+0.0303\cdot x-39.783$	$x\in[376\,ppm,\,1020\,ppm]$	$y\in[-30^\circ C,-20^\circ C]$
$y=-7\cdot10^{-5}\cdot x^2+0.0756\cdot x-48.302$	$x\in[127\,ppm,\,376\,ppm]$	$y\in[-40^\circ C,-30^\circ C]$
$y=-7\cdot10^{-4}\cdot x^2+0.2287\cdot x-57.767$	$x\in[40\,ppm,\,127\,ppm]$	$y\in[-50^\circ C,-40^\circ C]$
$y=-63\cdot10^{-4}\cdot x^2+0.6471\cdot x-65.819$	$x\in[10\,ppm,\,40\,ppm]$	$y\in[-60^\circ C,-50^\circ C]$
$y=-876\cdot10^{-4}\cdot x^2+2.3932\cdot x-75.341$	$x\in[3\,ppm,\,10\,ppm]$	$y\in[-70^\circ C,-60^\circ C]$

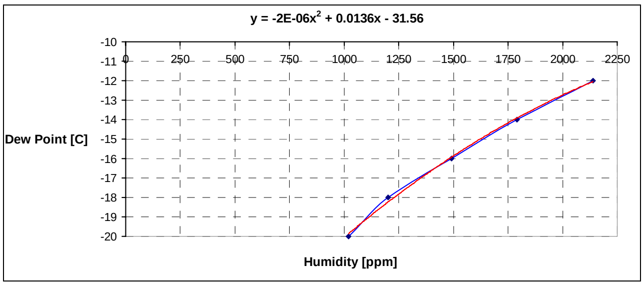

Figure 9. Dew point dependence on humidity for the dew point in a range $\left[-20^o C,\,-12^o C\right]$

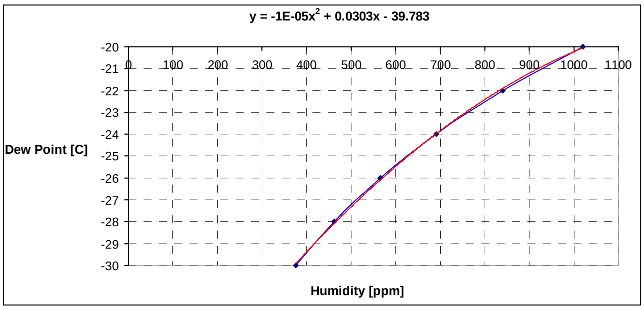

Figure 10. Dew point dependence on humidity for the dew point in a range $\left[-30^\circ C,\,-20^\circ C\right]$

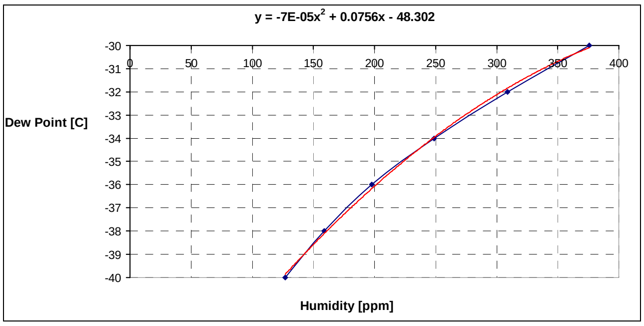

Figure 11. Dew point dependence on humidity for the dew point in a range $\left[-40^\circ C,\,-30^\circ C\right]$

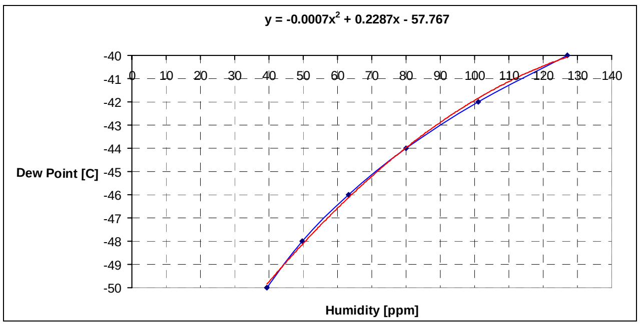

Figure 12. Dew point dependence on humidity for the dew point in a range $\left[-50^\circ C,\,-40^\circ C\right]$

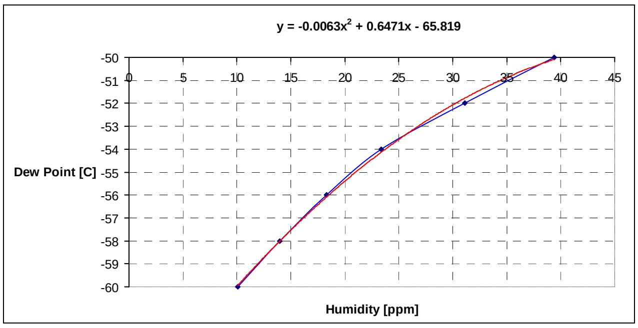

Figure 13. Dew point dependence on humidity for the dew point in a range $\left[-60^\circ C,\,-50^\circ C\right]$

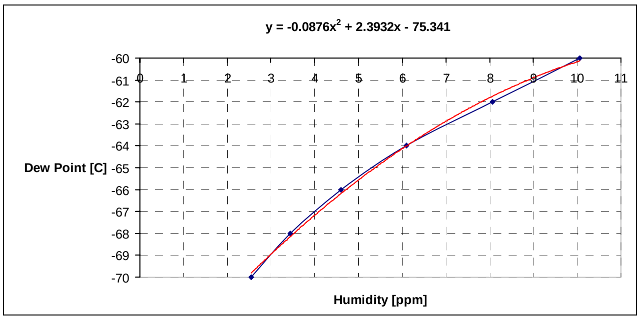

Figure 14. Dew point dependence on humidity for the dew point in a range $\left[-70^\circ C,\,-60^\circ C\right]$

Conclusion

This paper presents the equipment and the method of remote measurement of the dew point and humidity in the T-38 wind tunnel. Two contributions are presented in this paper. The first contribution is enabling remote measurement of humidity. Until now, the Aquanal hygrometer has only been used for local measurement. The second contribution, which is the main contribution of this project, is the conversion of the dew point from humidity by approximating pieces of non linear dew point dependence on humidity with square functions and calculating the value of the square function by the microcontroller. In the age of sophisticated equipment, a tendency is that all the sensors located remotely have the capability of remote measurement.

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Daljinsko merenje tačke rose pomoću akvanel higrometra

U ovom radu je predstavljen uređaj za daljinsko merenje tačke rose pomoću Akvanelov higrometra u aerotunelu T-38. Uređaj za daljinsko merenje tačke rose je razvijen u Vojnotehničkom Institutu. Aerotunel T-38 je koristi suv vazduh iz rezervoara od 2600 kubnih metara. Ideja projekta je bila da se omogući daljinsko merenje tačke rose. Nakon ove modifikacije Akvanelovog higrometra, operator kompresora će imati ispred sebe informaciju o tački rose vazduha. Akvanelov senzor se nalazi na izlazu iz rezervoara aerodinamičkog tunela T38.

Ključne reči: **aerodinamički tunel, daljinsko merenje, tačka rose.**

Дистанционное измерение точки росы с использованием акванел-гигрометра

В этой статье представлено устройство для дистанционного измерения точки росы с использованием конденсационного Акванел-гигрометра в аэродинамической трубе T-38. Это устройство для дистанционного измерения точки росы разработанно в Военно-техническом институте в Белграде. Аэродинамическая труба T-38 использует сухой воздух из резервуара в 2600 кубических метров. Идея проекта заключалась в предоставлении дистанционного измерения точки росы. После этой модификации Акванел-гигрометра, оператор компрессора перед собой будет иметь информацию о точки росы воздуха. Акванел-датчик расположен на выходе из резервуара аэродинамической трубы T-38.

Ключевые слова: **аэродинамическая труба, дистанционное измерение, точка росы.**

Mesurage à distance du point de la rosée à l'aide de l'hygromètre Aquanal

Le dispositif pour le mesurage du point de la rosée à distance à l'aide de l'hygromètre Aqanal effectué dans la soufflerie T-3 est présenté dans ce papier. Ce dispositif a été développé à l'Institut militaire technique, Belgrade. La soufflerie T-38 utilise l'air sec du réservoir contenant 9600 mètres cubes. L'idée de ce projet était de permettre le mesurage à distance du point de la rosée. Après cette modification de l'hygromètre Aqanel l'opérateur du compresseur aura devant lui l'information sur le point de la rosée de l'air. Le capteur du dispositif Aqanel est placé à la sortie du réservoir de la soufflerie T-38.

Mots clés: **soufflerie, mesurage à distance, point de la rosée.**