METHODOLOGY FOR MEASURING THE DEW POINT TEMPERATURE IN COMPRESSED AIR COMPRESSOR

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Abstract: Controlling dew point temperature of compressed air, which has been used in provision industry, is essential for the quality of its products. This technical paper proposes a method for calculating dew point temperature, considering its uncertainties. This methodology, which presents a possible systematic application, leads to guarantee such a metrology reliability of the results.

Key Words: Temperature, Statistics, Uncertainty, Metrology.

1. INTRODUCTION

The industrial manufacturing processes use compressed air as a kind of energy, which is similar to electrical energy and hydraulic one. In general, factories use to have a central unity for compressed air production and treatment. Due to the amount of energy necessary for operating the central unit for compressed air production and treatment, which is one of the main consumers of the factory, it is of relevance to improve its study. Reducing the energy costs of the compressed air central unity, it implies directly in cost reduction of factory production, then increasing competitiveness within the market industries. The parameter to be measured is the dew point temperature, which is given in Celsius degree (^{o}C). The lack of control of this parameter can lead to raising the electrical energy consumption due to the compressor, pneumatic system components corrosion as well as precocious drying of separated parts of the system. Temperature control is linked to the phenomenon of air condensation.

The aim of this technical paper is to compare the accordance within the industrial process and the on-design conditions of dew point temperature established by the compressor manufacturer, Atlas Copco. It is expected a temperature of about 4^{o}C ± 1^{o}C in the conception project, and also to attend the technical standard (NBR 9273, 1986) with respect to stability and reliability, [1].

2. METHODOLOGY

In the test realized during the Post-graduation Program of Mechanical Engineering of Federal University of Pernambuco (UFPE), it was used the air compressor of Atlas Copco, reference code GA 125 30FF. In order to work out the uncertainties of the results it was used the method "Guide of Uncertainty in Measurement", which is the international standard one in metrology, [2].

In order to confirm this hypothesis it was built a measurement system MS to measure the dew point temperature parameter. The MS system is composed by a thermometer which is has a bi metal rod (sensor), a set of axles and tabs (link), a bearing and transducer (unit converter), and a display, as shown in figure 1.

Figure 1. Measuring System - MS

The temperature parameter is measured in the compressor output just after the air dryer, according to the air compressor manufacturer's recommendation, Atlas Copco. In this way, the spatial variable is referred to a single point. The temporal variable, which is subject to condensation phenomena of the air extracted from the environment, is dependent of meteorological conditions, so 730 indications were realized in one year period.

The other variables that interfere in the measurement result MR were obtained by consulting technical standards and manufacturer's information. The bi metal thermometer from the manufacturer Tecno Vip, reference code TEC-2390 has a measurement uncertainty of about ($T\pm2^{\%}$), according to information in its internet website, [3]. The environment uncertainty has a measurement uncertainty for the dew point of about ($T*10^{\%}$)°C, (NBR 9273, 1986), [4].

For considering the uncertainty of repetitive measurements, the following statistics conditions were applied as explained below.

As more than one hundred indications were realized, it is recommended the procedure of statistic analysis by sampling. Based on the statistic it was proposed realizing a previous experiment of a sampling with size n=40, randomly extracted from raw data (730 indications), and use sample mean estimator for the mean value $\bar{x}$ and the sample standard deviation estimator σ. In order to determine the value of n it was used the Operational Characteristic curve (OC) for normal bilateral t test and significance level α=0.05, the value $d=(\mu-\bar{x})/\sigma$ for ordinate, and accepted the probability value of Ho=0,1 for ordinate, so allowing to determine the sample size [5].

By determining the sample size it was proposed a test plan using five replications with independent estimations. The mean values of these samples of size n were obtained from the OC curve and were combined to provide statistic estimation even better than the experiment of the variable measured by a single sample. Therefore, samples of equal size are grouped to form a common set of combined statistic defined by the combined average $<\bar{X}>$, combined standard deviation $<s_x>$, and with degrees of freedom ν= M(N-1) and combined standard deviation of the means $<s_{\bar{x}}>$ [5].

3. UNCERTAINTS AND RESULTS

The answer which has been looked for is of a kind of direct measure containing uncertainties due to multiple measurements. These measurements were realized in such a time interval and occurred with elementary error propagation of data acquisition and external variables. The multiple measurements lead to repetitive errors here defined as being of "A" type. The random errors from acquisition data are here defined as being of "B" type. The "B" type error is composed by errors of "BP" type, which involves random uncertainties of patterns and also by errors of "BS" type, which involves systematic uncertainties [1].

It was also used the statistical sample analysis method, taking into account 730 gross data. Once it has been assumed at least an approximate normal distribution with unknown variance, it must be analyzed as a hypothesis test for the population mean and with error probability of type "II", of bilateral alternative. The solution takes into account a previous experience to determine the adequate sample size in order to provide the required sensibility [5].

The previous experience is a preliminary sample of arbitrary size and randomly obtained from gross data in order to get its mean value and its standard deviation, which have been used in determining the sample size for the experiment of working out the temperature. It has been prepared a preliminary sample of 40 data, which have been shown in table 1, as follows, relating temperatures in °C.

Table 1. Sample of 40 Temperature Data in °C

3.78	**3.06**	**3.45**	**3.82**	**4.31**	**3.28**	**3.38**	**3.12**
3.65	**3.28**	**3.06**	**3.40**	**3.82**	**3.64**	**3.89**	**3.08**
3.24	**4.02**	**4.39**	**3.54**	**3.16**	**3.26**	**3.85**	**3.06**
3.41	**4.08**	**3.09**	**3.02**	**3.12**	**3.03**	**3.24**	**3.88**
3.43	**3.10**	**4.19**	**3.08**	**3.81**	**4.02**	**3.41**	**3.04**

Table 2, as follows, presents parameters of the problem, which include values of sample mean and standard deviation and other known data that have been used for calculating measurements results.

Table 2. Parameters of the Problem

Preliminar Experiment Experimento preliminary		
Sample size	**n**	**40**
Sample mean	$\bar{x}_p$	**3,4872**
Standard deviation	s_p	**0,40203**
Known Data		
Dew Point Temperature	**μ**	**4 °C**
Project Tolerance	**TP**	**(3 a 5) °C**
Reliable interval	**IC**	**95%**
Acceptance Probability	**Ho**	**0,1**
Measurement error $(\bar{x}-\mu)$	**δ**	**0,51275**
Abscissa = δ/ s	**d**	**1,2754**

3.1. Choosing the Sample Size

In order to determine the sample size for calculating the measurement result MR it has been used the recommended method available in the reference *Annals of Mathematical Statistical*. It has been used the sample standard deviation s_p=0,40203 to estimate σ and to get the abscissa value of the Operational Characteristic Curve of graphic VIIg for bilateral t-test with significance level of α=0,05 [5]. In this graphic, which has an abscissa value d=1,275 and an ordinate whose acceptance probability value H_o=0,1 leads to choosing the curve of n=10 as a result.

Assuming a sample size of n=10, it has been proposed a test plan which uses five responses with independent estimative. The mean value of these samples with size n=10 has been combined to provide an statistical estimative better rather than the experiment of the measured variable by a unique sample. The samples of equal size have been grouped and form a common set of combined statistic, which has been defined by the combined mean $<\bar{x}>$, combined standard deviation $<s_x>$, and degrees of freedom υ= M(N-1) and the combined standard deviation of means $<s_{\bar{x}}>$, [1].

The values of sample size and their means and standard deviation for the five samples obtained from the gross data are shown in table 3, as follows, defined as *The five samples of size 10*.

Tabela 3. The Five samples of size 10

N/M	m1	m2	m3	m4	m5
n1	3,060	3,500	3,800	3,040	3,020
n2	3,280	3,820	4,100	3,500	3,760
n3	4,020	3,060	3,080	3,040	3,240
n4	4,080	3,050	3,060	3,080	3,020
n5	3,100	4,020	3,880	4.060	4,050
n6	3,280	4,030	3,040	3,980	3,020
n7	3,640	3,820	3,060	3,440	4,820
n8	3,260	3,400	3,090	3,880	3,340
n9	3,300	3,540	3,080	3,240	3,210
n10	4,020	4,120	3,500	3,020	4,020
Média	3,504	3,636	3,369	3,428	3,550
DPA	0,401	0,389	0,413	0,413	0,598

The answer which has been looked for is of a measuring that is a direct measure containing uncertainties and multiple measurements. These measurements were realized within a time interval, and contain elementary error propagation from the data acquisition. The multiple measurements lead to repetitive errors, here defined as "A" type, and also lead to elementary errors from acquisition data, here defined as "B" type.

The estimated temperature has been obtained by using a temperature probe positioned in such a local according to manufacturer recommendation and errors sources. This explicit value has been determined by using equation (1), as follows.

$$\mathbf{MR = T = < \overline{T} > \pm U_T} \qquad (1)$$

3.2. Calculating the Mean Temperature

The value of basis result $\overline{T}$ is worked out from the 5 samples of 10 indications of T variable, which has been repeated in order to provide the set of data presented in table (3). The combined mean of T is defined by equations (2) and (3).

$$\overline{T}_N = \frac{1}{N}\sum_{n=1}^{N} T_n \qquad (2)$$

$$\langle \overline{T} \rangle = \frac{1}{M}\sum_{m=1}^{M} \overline{T}_N = \frac{1}{5}\sum_{m=1}^{5} \overline{T}_N = 3,497 \qquad (3)$$

3.3. The magnitudes of influence and their contribution to the value of uncertainty

The magnitudes which influence the uncertainty are determined from independent variables and are classified by their types according to shown in table (4), as follows, which specifies sources of errors.

Tablea 4. Sources of errors

Sources of errors	Type	
Repetitive	A1	
Sensor stage (instrument error)		BS1
Environmental effect		BS2
Error due to spatial variation		BS3

All the other sources: measuring system operational conditions such as: signal conditioning stage and output stage (instrument errors), process operating conditions, sensor installing effect and errors due to time variation have not been taken into account in this experiment.

The repetitive occurrence is due to temperature measurements which cause data spreading. This occurs due to variations in the compressor control. The value of uncertainty contribution due to repetitive occurrence u_A is worked out from the 5 samples containing 10 indications of T variable, which has been repeated in the way to provide the data set presented in table (3). From these data it can be calculated: combined standard deviation $<s_x>$ with degrees of freedom υ= M(N-1) and the standard deviation of means $<s_{\bar{x}}>$, defined by equations (4) and (5).

$$S_T = \sqrt{\frac{\sum_{n=1}^{N}(\overline{T}_n - \langle \overline{T} \rangle)^2}{9}} \qquad (4)$$

$$u_{A1} = \langle S_{\overline{T}} \rangle = \sqrt{\frac{\sum_{m=1}^{5}\sum_{n=1}^{10}(\overline{T}_{mn} - \langle \overline{T} \rangle)^2}{M(N-1)}} = 0,088\ ^{o}C \qquad (5)$$

Those uncertainties of error instruments and those of environmental effects have rectangular distributions. They are calculated by using equation (6), for a standard deviation [2].

$$u_a = a/\sqrt{3} \qquad (6)$$

The instrument error is an uncertainty which occurs from elementary errors of the set of sources of acquisition data. In the sensor stage of the thermometer the error is considered of being of "BS1" type as it was provided by the thermometer manufacturer, which does recommend an uncertainty in the measurement of about $u_{BS1}=u_t=T\pm 2\%$ [3].Equation (7), as follows, shows the way of obtaining this value.

$$u_t = (\overline{T}x2/100)/\sqrt{3} = 0,04038 \qquad (7)$$

The uncertainty due to environmental effects is shown in the Brazilian Rule NBR 9273- Gases- Determining the amount of water by using the dew point method. This rule does recommend an uncertainty in measuring the dew point of about (T*10%). As one has not statistic information it is considered a systematic uncertainty of "BS2" type [4]. As for 2a= (T*10%), the contribution of a rectangular distribution is given $u_{BS2}=u_H= a/\sqrt{3}$. Equation (8), as follows, shows the way of obtaining this value.

$$u_H = (\overline{T}x10/100)/\sqrt{3} = 0{,}100961 \quad (8)$$

For this experiment there is no contribution concerning spatial error because the probe is positioned in such a local in the compressor exit, after the air dryer [6].

3.4. Calculating the measurement result

Table 5, Errors Uncertainties of “A” and “B” types, as follows, shows the sources of errors of “A” type (repetitive), the sources of errors of “B” type (instrument and environment), respectively, the nomenclature, the estimated value of each uncertainty ($u_{estimate}$), type of statistical distribution, probability divisor,, value of contribution coefficient (CI), the standard uncertainty and degrees of freedom considered in each distribution.

Tabela 5. Errors Uncertainties of “A” and “B” Types

Source	Nom.	u_{esti}	dist	div	CI	$u_{standard}$	υ_{eff}
Repetitive u_A	$<s_{\overline{T}}>$	0,088	N	1	1	0,088	45
Thermometer u_{BS1}	T±2%	0,069	R	1,73	1	0,0404	∞
Environment u_{Bs2}	T*10%	0,174	R	1,73	1	0,101	∞

4. CONCLUSION

The value of standard result $\overline{T} = <X>$ is worked out through the combined mean of the samples. Table 7, as follows, shows grouped values of a common set of combined statistic defined by the combined mean, degrees of freedom and combined standard deviation of the means.

Table 7 - Results of means, degrees of freedom and combined standard deviation of the means.

Combined Mean $\overline{T} = <\overline{X}>$	$<\overline{X}>$	**3,497**
Degrees of Freedom	ν=M(N-1)	**45**
Combined Standard Deviation of the Means	$u_A = <s_{\overline{x}}>$	**0,088**

For determining the uncertainties, the source of the thermometer was extracted from the manufacturer statement S1 whose value is T±2% and P1=0, the latter due to the lack of statistic information; and the environment source is a standard statement S2, whose value is T*10% and P2=0, again due to the lack of statistical information. The spatial source P3 is a measuring single point (thus it does not have spatial variation), adding up an uncertainty of B type. The total contribution of A type is the repetitiousness, which is calculated as the uncertainty u_A shown in table (8).

Table 8, as follows, shows the final results of measuring results MR as well as the combined uncertainty estimated by uc. The expanded uncertainty U is the product of range factor “K” multiplied by combined uncertainty uc. This “k” factor obtained from t-student table in the column referred to reliable level 95 % and the effective degrees of freedom (υ_{eff}), which has been estimated by using the Welch-Satterhwaite equation.

Table 8 - Final Results of the Measuring Results MR

Symbol	Component of uncertainty	Probability Distribution	u	Degrees of Freedom
	Source	Type	$u_{i[\ ]}$	ν_i or ν_{eff}
u_A	Repetition	Normal	0,0881	45
u_t	thermometer	Rectangular	0,0404	∞
u_H	environment	Rectangular	0,1009	∞
u_c	Combined uncertainty	Normal	0,13998	
U	Expanded uncertainty	Normal k=2;P=95%	0,2799	286
MR	MR= ($\overline{X}$±U_{95}) (k;P)		(3,50±0,28)°C (k=2; P=95%)	

The measurement result, in an explicit way, takes into account rounding rules and compatible values of about T= (3,50±0,28)°C (k=2; P=95%).

After obtaining the results, it is noted that the temperature variation which has been calculated is within the estimated interval, once the project conceiving considers an interval of about from 3°C to 5°C, and it was found an interval of about from .3,22°C to 3,78°C. For the parameter of the project, 4°C, the result of the mean of the experiment was 3,50°C, and the estimative error $\mu - \overline{X}$ = 0,50°C, which can be originated from the extrinsic variables.

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