DFA concepts applied in development of accessories for calibration

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Abstract. The purpose of this paper is to identify design requirements of a device to be used as an accessory in calibration. In this case study, a simple device to sample atmosphere from humidity generators used to calibrate air humidity meters is developed and it is proposed a model applying Design for Assembly concepts.

1. Introduction
The Physical Metrology Laboratory (MTF), part of the National Institute for Space Research (INPE)/Integration and Testing Laboratory (LIT), is responsible for calibrating sensors and equipment used by INPE, private companies, universities and other research institutes. Its area of actuation is acoustics and vibration, temperature, humidity and vacuum.

Calibration of humidity sensors and hygrometers are usually performed through comparison between the indication of the device under calibration and a conventional value indicated by a standard traceable to the International System (S.I.), using a calibration chamber with stable and controlled humidity.

The aim of this paper is to apply some general concepts from Design for Assembly (DFA) methodology to guide the design of an optimized device to be used in humidity calibration, specifically in dew point calibration.

2. Design for Assembly
DFA is a systematic method derived from Design for Manufacturing (DFM), in which great improvements come from simplifying the product through minimizing the number of separate parts.

Boothroyd and Dewhurst DFA methodology purposes three criteria to guide the analysis for each product part in the assembly [1]:

a) Does the part have relative movement to the other parts of the product?
b) Does the material have to be different from the other parts already assembled?
c) Does the part have to be separate from others to allow product assembling and disassembling?

Any affirmative answer to those questions indicates that the part shall be separate.

Some of good practices to achieve improvements in product design are [2]:

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• Easy handling and assembling of the product due the small number of pieces;
• Modular design and the possibility of product variants from new parts to be integrated in the future;
• Choose the material by function and process;
• Parts that cannot be assembled incorrectly;
• Efficient use of fixation techniques and
• Use of gravity.

At this point, manufacture feasibility is not considered. However, feasible ideas can arise [1].

3. Humidity measurement
Humidity measurement can be made by total or partial immersion of the probe or sensor in the environment to be measured, or by collecting a sample of air from this environment through a pipe. Two methods are widely used for generating humidity calibration environment: the use of climatic test chamber and the use of generator dewpoint [3]. For best results, it is recommended to place the sensor as close as possible to the point of measurement. When using a climatic chamber, for instance, the sensor can be placed inside the environment to be measured. Collecting a sample of air from the environment is the most appropriate method in cases in which it is needed to measure the temperature and dew point and the gas is contaminated, with filtering possibility, and when the gas temperature is higher than limit sensor operation [4]. It is also necessary to sample the atmosphere when the dew point generator does not provide a measuring chamber for the sensor to be calibrated. To solve this problem, the flow of air generated can be driven by the item being calibrated and the working standard, enabling the comparison of both [3].

In the calibration of optical dew point hygrometers it is necessary to use a measuring chamber, which will receive the gas sample and should provide the same dew point conditions from the generator. For a measurement of dew point close to the true value, sampled gas shall be conducted from its source to the sensor mirror without distortion of the partial pressure of water vapor [5]. Some dew point meters already have small measurement chambers.

Even if the sensors used in measurement have a very low response time, there may be a delay or failure in the correct measurement of humidity, especially at low values. This is due to several factors that should be considered in sampling gas from the environment to be measured.

Any type of contaminant should be avoided, including sources of water vapor. The lower the humidity to be measured, the most accurate care is demanded with the measurement environment [3]. There are specific recommendations for each measurement range. To minimize contamination, the sensor mirror should stand in the vertical position. If the temperature of dew point of the gas is higher than the room temperature, it shall be provided heating of the sampling line and the sensor in order to avoid condensation of the measurement gas [4].

The number of connections shall be reduced to minimize the leakage of moisture and dead ends should be avoided as they hinder the removal of moisture from the system [3]. The impact of leaks is inversely proportional to the dew point temperature to be measured, being very significant in the negative range [4]. Another source of moisture that should be minimized is the feedback, i.e., the return of water vapor after the sensor into the system. A good practice is the use of long exhaust pipe after the sensors. The choice of materials used in measuring low humidity is also of great importance for the efficiency of the system. Use of hygroscopic materials shall be avoided [3]. Material absorption/desorption characteristics affect the system as a whole [4]. Stainless steel and nickel are considered virtually impervious, what make them recommended for this application. Comparatively to steel, polytetrafluoroethylene (PTFE) is very permeable. Although, among the polymeric materials it is suitable for measuring humidity to -20 °C dew point and in some cases even slightly below this value [3]. Most plastics and rubbers are not suitable for measuring any moisture range [4]. Figure 1 shows the performance of various materials in moisture removal in a measurement system.
4. Case study
INPE/LIT has a dew point calibration system (DCS) comprising a dew point optic hygrometer and a port to carry the calibration gas. The item under calibration shall be exposed to the calibration gas. This was the reason to design a device for sampling the gas and put it in contact with the sensor.

Initially, two sensors used by INPE/LIT as humidity working standards were chosen. The sensors under calibration using the sampling device have different measuring principles, operation and dimensions. The first sensor (Sensor A) is a two stage cooled mirror optical dew point sensor part of a dew point hygrometer model Optidew Vision by Kahn Instruments, Figure 2. The second sensor (Sensor B) is a capacitive humidity sensor model HC2-IC105 by Rotronic, Figure 3.
Table 1. Technical data of sensors under calibration

| Feature                              | Sensor A          | Sensor B          |
|--------------------------------------|-------------------|-------------------|
| Sensor type                          | Optical           | Capacitive        |
| Dew point working range              | -40 a +60 °C      | -40 a +60 °C      |
| Application                          | Working standard for humidity calibrations | Humidity monitor for EMI/EMC tests |
| Sensor length                        | 63 mm             | 100 mm            |
| Sensor diameter                      | 28 mm             | 15 mm             |
| Mechanical connection                | M36x1.5-6g        | Fitting           |
| Minimum immersion depth for measuring| 74 mm             | 39 mm             |

Based on the application, three attributes were considered more relevant in this case: efficiency, ease of operation and adaptability. This decision led to a list of desirable characteristics, as shown in Figure 4.

![Sampling device](image)

**Figure 4.** Desirable characteristics for the humidity sampling device

The efficiency of the device is strongly linked to the prevention of unwanted sources of water vapor as points of accumulation of moisture absorbed or adsorbed and entry points for moisture. Once these sources, in addition to increasing the settling time of the system, can introduce errors and increase the measurement uncertainty, the proposal is to minimize its occurrence.

From the characteristics of the sensors to be calibrated, the moisture range defined in this work and the desirable characteristics of the device, project requirements were identified:

- The device must have only non-hygrosopic materials.
The device must have connections only at the points where there is input or output of gas and where the sensor is installed.

- The device must allow entry and exit of gas.
- The device should allow the installation of a moisture sensor in the horizontal direction.
- The device must have a pipeline to carry gas from the generator dew point until its entry.
- The device must have a duct in the output.
- The device should allow installation of sensors with diameter up to 28 mm.
- The minimum immersion depth of the sensor in the measuring chamber shall be 39 mm.
- The device must meet the range of -40 to +20 °C dew point temperature.

Starting with the choice of materials, the option was for the use of stainless steel and PTFE. The use of PTFE was admitted as possible because its characteristic absorption and desorption of moisture is at the limit to the range of this work.

The suggested initial setting is shown in Figure 5. In this configuration the device comprises:

- 01 measuring chamber with a gas inlet connection with thread, a connection for gas outlet with thread and with an open face to allow installation of different lids.
- 01 lid with hole for Sensor A.
- 01 lid with hole for Sensor B.
- 01 pipe for connection to the dewpoint generator, threaded at both ends.
- 01 pipe for connection to the output of the measuring chamber to avoid feedback.
- 04 screws on the lids.

![Figure 5. Preliminary design](image)

The fastening of the lids in this configuration is a problem for the efficiency of the system because of the sealing and the assembling requires a tool and alignment. The number of connections can also be a problem.

Applying the criteria proposed in Boothroyd Dewhurst DFA method it was observed that some parts could be unified. Based on the criteria presented in Section 2 the analysis is presented in Table 2.

When applying DFA it was noticed that a change in the concept of the chamber could make it possible to remove the lid dedicated to Sensor A. Therefore, the interior of the measuring chamber was based on the dimensions of the Sensor A, which has a thread on its body that enables easy connection to the calibration medium, as shown in Figure 2.
The lid for the Sensor B can not be ruled out. However, as this sensor has a smaller diameter than the diameter of the sensor A, it was possible to alter the geometry and the way of fastening this lid. Making it circular with the same external diameter and thread from Sensor A, the four holes and screws could be removed.

| Part                | a) relative movement | b) different material | c) must be separate |
|---------------------|----------------------|-----------------------|---------------------|
| Measurement chamber | no                   | no                    | yes                 |
| Lid - Sensor A      | no                   | no                    | no                  |
| Lid - Sensor B      | no                   | no                    | yes                 |
| Inlet pipe          | no                   | no                    | yes                 |
| Outlet pipe         | no                   | no                    | no                  |
| Screws              | no                   | no                    | yes                 |

The inlet pipe for connection to the dew point generator must remain separate as it can be used for calibration of sensors that have their own measuring chambers. Furthermore, it can be replaced anytime by another tube of the same material or different material, increasing the flexibility of the system.

The outlet pipe has to minimize the retroactivity single function and can be part of the measuring chamber, reducing one step in assembly and disassembly and also reducing connection in the system.

The new configuration is shown in Figure 6.

**Figure 6. New design after DFA**

Modifications after applying the DFA resulted a device with the following parts:

- 01 measuring chamber with a gas inlet connection with thread, a welded gas outlet pipe to minimize feedback, a hole with a M36x1.5 thread for installation of sensor or lid.
- 01 lid with external M36x1.5 thread and drilling for Sensor B.
- 01 inlet pipe for connection to the dew point generator, threaded at both ends.

The external geometry of the sampling device has been chosen to dispense the use of supports which give stability to the assembly.

5. Conclusion
Some requirements for the sampling device are quite obvious, because they are identified with the characteristics of the sensors and the working range defined by the user. However, after studying the factors that can influence the performance of the calibration system as a whole, it has been found necessary to include requirements disregarded in the initial analysis.
Although DFA aim is to simplify the assembly of products, in order to simplify manufacturing, its application in this study guided the design of the sampling device to meet the identified metrological requirements and improve its operational ease.

The criteria proposed by Boothroyd and Dewhurst DFA method were effective in decreasing the parties that may affect device performance, particularly in the reduction of points accumulation, leak or desorption of water vapor. The proposed model after applying DFA meets the requirements of the project and should be submitted in the next step of the manufacturing feasibility analysis, which was not considered in this work.

There is a significant indication that DFA can be applied in others areas of metrology to help in the design of optimized accessories for calibration.

References

[1] Boothroyd G 1996 Design for Manufacture and Assembly: The Boothroyd and Dewhurst Experience Design for X: Concurrent Engineering Imperatives ed Huang G Q (London: Chapman & Hall)
[2] Leaney P G 1996 Case Experience with Hitachi, Lucas and Boothroyd-Dewhurst DFA Methods Design for X: Concurrent Engineering Imperatives ed Huang G Q (London: Chapman & Hall)
[3] National Physical Laboratory 1996A Guide to the Measurement of Humidity (London: The Institute of Measurement and Control)
[4] Cortina V B 1985 Sampling Systems for Chilled Mirror Dew Point Hygrometers Moisture and Humidity Measurement and Control in Science and Industry: Proc. of the 1985 International Symposium on Humidity and Moisture (Washington D.C., USA, 1985) ed Instrument Society of America (Durham: Instrument Society of America) pp 849-51
[5] Paine L C, Farrah H R 1965 Design and Applications of High-Performance Dew-Point Hygrometers Humidity and moisture: measurement and control in science and industry ed Wexler A (New York: Reinhold Publishing)